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# Air-Cooled Storage For Apples

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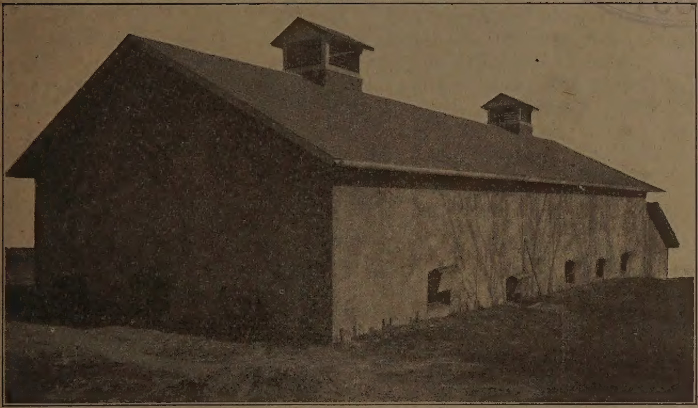

AGRICULTURAL EXPERIMENT STATION

MICHIGAN STATE COLLEGE

Of Agriculture and Applied Science

HORTICULTURAL SECTION

East Lansing, Michigan

# Air-Cooled Storage for Apples

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The problem of keeping fruits in warehouses is one which includes proper regulation of (1) temperature, (2) humidity, and (3) air circulation. It is necessary to maintain temperatures low enough to retard the ripening of the products and to check the development of fungi and high enough to prevent freezing. This may be done by taking air into the storage room when the outside temperatures are closest to those desired and excluding air when they depart from the optimum storage temperature for the stored product. Humidity must be regulated to keep the air of the warehouse moist enough to check wilting or shriveling of the fruits and yet dry enough to prevent the growth of molds and fungi. This is accomplished by ventilation, by evaporating water in the room or by absorbing the excess moisture. Gaseous products, resulting from the ripening processes of perishable products, may accumulate in excess quantities in portions of a storage room unless the air of the room is circulated or the warehouse is ventilated. Successful storage, therefore, contemplates a proper balance of temperature, humidity, and air circulation.

The term "cold storage" usually has reference to the storage of products in rooms cooled by means of mechanical refrigeration. This is the ideal kind of storage but the costs of construction and operation are excessive for the grower or growers' organizations with less than 25,000 bushels of late maturing fruits.

Unheated cellars have been used for apple storage with various and varying degrees of success. In the days of Ben Davis and the russet apples, which were grown largely because of their excellent keeping qualities, cellar storage seemed fairly adequate. Present conditions, however, have made it necessary to provide the market with other varieties, even late in the season; for these apples, cellar storage is not adequate.

An ordinary cellar may be frost proof and still be wholly inadequate for apple storage, because it does not provide sufficient air change (1) to cool the fruit sufficiently during the fall, (2) to regulate humidity and (3) to remove deleterious gases given off by the fruits. The first important improvement consisted of introducing outside air into the cellar through one or more long lines of small tile which were laid underground. Small ventilators extending from the ceiling of the room through the earth covering of the cellar allowed the warmer air and the gases resulting from the ripening and decaying of the fruits to pass off. This system made possible the introduction of a small amount of air at any season of the year and provided for a circulation of air within the cellar.

Better distribution of the air was obtained in some cellars by building air deflectors above the entrance of the air intakes, or by placing the air intakes and ceiling ventilators or in outlets at opposite ends of the cellars, or by alternating them in the larger cellars. Storage B* was originally constructed with a tile intake and had a motor driven fan at the cellar end of the tile to increase the rate of air movement. In a few cases the incoming air was made to pass over a small vat of water to increase its humidity and thus lessen the degree of wilting of the products.

From this cellar type of storage, the partly underground and the above ground common or air-cooled storages have gradually been developed more or less simultaneously in several parts of the country, but more particularly in the Northeastern, Appalachian, and Northwestern apple districts where cool nights prevail during the fall months. Storage A was probably the first of this modern type to be built in Michigan and much of the recent interest in air-cooled storages in this state is due to the fact that this one has been very successful.

## THE PRINCIPLES INVOLVED IN THE VENTILATION OF AIR-COOLED STORAGE

Other conditions being equal a cubic foot of cold air is heavier than the same volume of warm air. If then air with a temperature of say 45° F. comes in contact with fruits or vegetables whose temperature is 50° F. the air absorbing some heat from the stored product, expands, and becoming lighter it consequently rises, thus permitting more of the colder air to move toward the apples. In this way a circulation of air is started which continues as long as the fruit remains warmer than the air surrounding it.

The air-cooled storage is designed to take advantage of this principle. Air is taken in through several openings or air intakes built in the walls just above the ground level or near the floor of the structure and it leaves the building through ventilators, or air outlets, which extend from the ceiling of the fruit room through the roof of the building. (See Figure 1.†) Both the cold air inlets and the outlet flues are equipped with tight doors which serve as dampers to permit entrance of or to exclude the outdoor air.

When the outdoor air temperatures are lower than those in the storage room or of the fruit, the air inlet doors and those of the outlet flues may be opened permitting the warmer (and lighter) air of the storage room to pass out through the flues and an equal volume of the colder air to enter the room through the openings near the ground

*The capital letters appearing throughout this bulletin refer to storages listed in Table 2 on pages 28 and 29.

†Many of the older, common storages of New York are of the basement type. They have several large ventilation openings through the thick stone walls at the ground line or near the top of the storage room, but they do not have ceiling ventilating flues. A large volume of air passes through these storage rooms when the wind is blowing. In this case, the warmer and lighter air of the room rises and is blown out the openings on the leeward side of the room and the incoming cooler air settles to take its place. (See Figure 28.)

level. If, however, the outdoor temperatures become higher than those in the storage, the colder air of the storage will pass out through the lower openings and the upright flues will become inlets for warmer air from the outdoors, resulting in a warming rather than cooling of the fruit. Consequently all openings must be tightly closed whenever outdoor temperatures are higher than those inside the room, or warming rather than cooling of the fruit will follow.

Barring the influence of wind and the size of openings the rate of air movement through the storage room will be governed (1) by the difference between the outdoor temperature and that of the air of the storage room, (2) by the distance from the floor of the room to the top of the outlet flue, and (3) by the length of the outlet flue.

The storage must be so constructed that the temperatures obtained

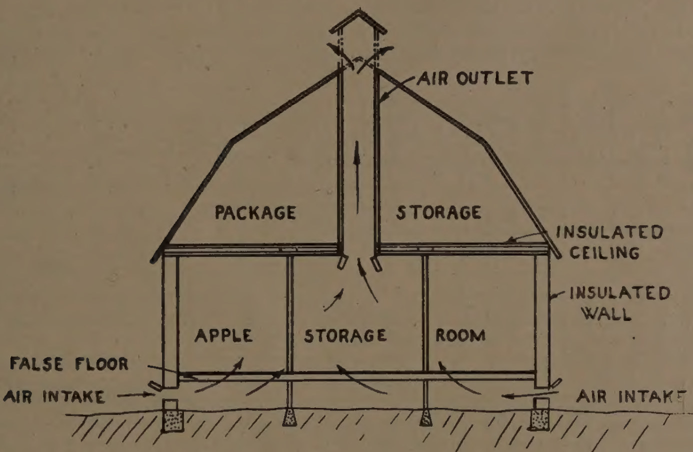


Fig. 1.—A typical storage house, shown in cross-section, illustrating the principles involved in the ventilation system. Open the air intakes and outlets whenever the outdoor temperatures are lower than those in the storage; close them when the reverse conditions obtain, until the desired storage temperature is reached.

when the inlets and outlets are open may be maintained. In other words, there should be little change in temperature when the outdoor temperatures are higher than those in the storage or when the outdoor temperatures are below the freezing point. Methods of securing the necessary insulation to favor the condition will be discussed in another part of this bulletin.

## THE RATE OF RIPENING IN STORAGE

All changes associated with the ripening of apples progress much more rapidly after picking than previously. However, the lower the temperature at which the fruits are held after picking the more slowly

the ripening processes take place. Magness (6) found that Jonathan, Delicious, and Rome Beauty softened more in two weeks when held at 60° F. than in four months at 32° F. and that Winesap, York Imperial, and Yellow Newtown were softer after one month's storage at 50 to 60° F. than after a storage of five to six months at 30° F. As a matter of fact, he found that the rate of softening or ripening, after picking, is entirely governed by temperature.

## TEMPERATURES MAINTAINED IN COMMON STORAGES IN AUTUMN

The temperatures that may be maintained in common storages depends upon the seasonal outdoor air temperatures, the type of storage house, the efficiency of the insulation and the management of the house.

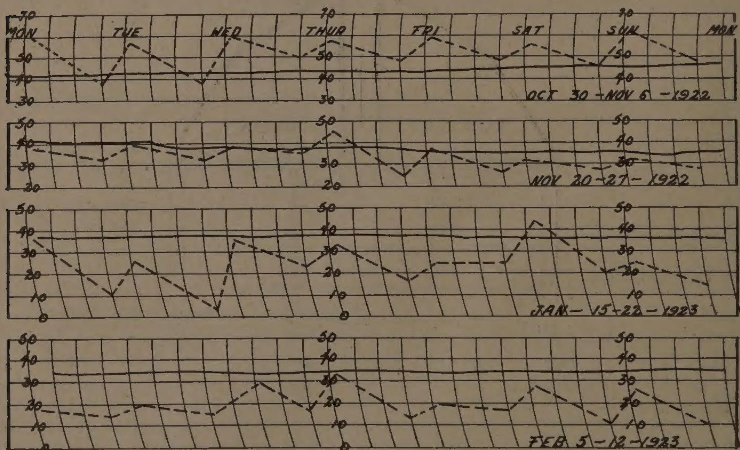


Fig. 2.—The solid line shows the temperatures as recorded in storage A during four weeks of the season of 1922-1923 and the broken line shows the daily maximum and minimum temperatures reported by the U. S. Weather Bureau at Grand Rapids. (12 miles southeast). Same comment as for Figure 4.

It is not difficult to maintain the temperatures during the winter months which compare favorably with those in cold storage rooms, but previous to late November or early December those of the air-cooled storage can be held but little below the average of the mean daily temperatures.

Marble (9) found the temperatures in a cellar storage in the north-central part of Pensylvania to follow closely the general temperature of the season, although it did not respond to sudden drops of outdoor temperatures because that of the storage was greatly influenced by the earth surrounding the room. The mean monthly temperatures of the

storage room were as follows: September, 60° F.; October, 55° F.; November, 45° F.; December, less than 40° F., and January and February, 34° F. to 38° F. Magness and Burroughs (7) working at the Marble storage report the cellar temperatures to closely approximate the mean of the outdoor temperatures, provided the cellar doors were standing open during the cooler portions of the day.

Cole (4) found that temperatures of 38 to 40° F. were usually obtainable during the fall months in Massachusetts if the storages were properly managed, and Baker (1) in Indiana states that the storage rooms cannot be cooled lower than 5 to 10° F. above the minimum night temperatures during the early storage season.

During the early part of the storage season of 1922-1923, recording thermometers were operated in two storages in Kent County and in one Lenawee County storage for the purpose of learning the tempera-

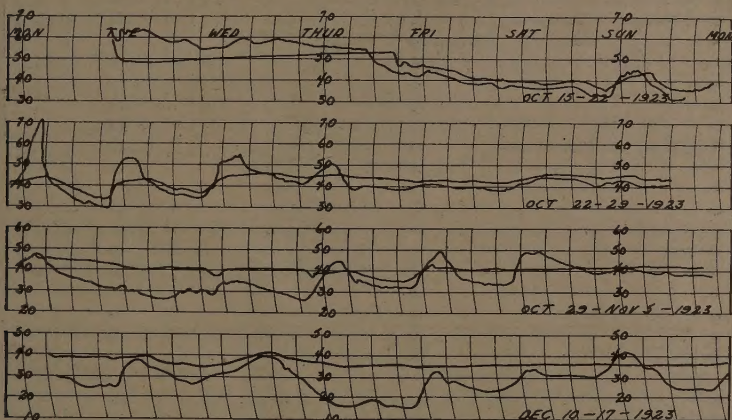

Fig. 3.—Outdoor and storage room temperatures recorded at storage A during four weeks of the season of 1923-1924. Same comment as for Fig. 4.

tures that are actually obtained during fall months under Michigan conditions and to ascertain whether or not freezing temperatures are ever experienced during the coldest periods of the winter. Outdoor temperatures for that season were not recorded at the storage locations, but were obtained from the nearest U. S. Weather Bureau stations. During the following storage season both outdoor and storage temperatures were recorded at two storages located in Kent and Lenawee Counties and storage temperatures were recorded for parts of the season in three other storage houses. The recording of outdoor and storage temperatures was repeated during 1924-1925 in one of the Lenawee storages Tables 14 to 17 inclusive (see appendix) show the daily range of temperatures for two of the storages where the records were obtained for longer periods of time. Figures 2 to 5 show the temperatures as recorded on the thermograph record sheets for certain weeks when temperatures of the outdoors were rather unfavorable for the maintenance of proper storage temperatures.

The late fall of 1922 was characterized by rather uniformly cool, but not cold, nights until November 24 when the outside temperature dropped below 30° F. for the first time (see appendix Table 14). During the period October 28 to November 24 the storage temperature gradually declined from 47 to 35° F., the latter being the point at which the owner attempted to hold his storage during the winter. In other words,

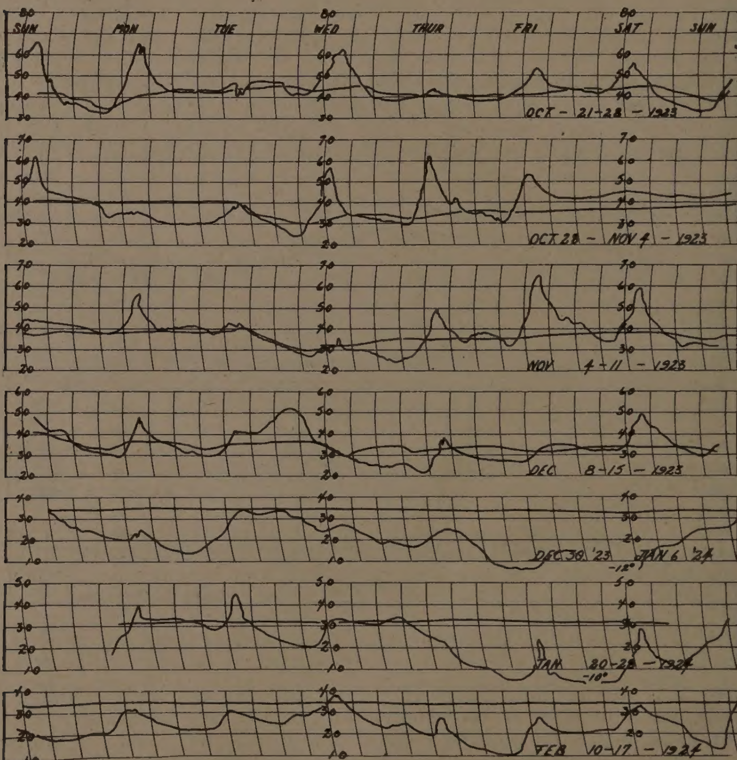

Fig. 4.—Outdoor and storage room temperatures recorded at storage E during seven weeks of the season of 1923-1924. The storage room temperature (indicated by the straighter line) was slightly below the mean of the outdoors until it reached 35 to 32° F. The temperature during the winter months was nearly uniform and just above freezing.

conditions approximating those in cold storage rooms were maintained after November 24.

The fall of 1923 was characterized by greater daily fluctuations of outdoor temperatures and there were several days during the latter part of October and November when the temperatures dropped below freezing. Consequently, conditions were more favorable for an earlier cooling of the apples in the storage houses.

A comparison of the storage temperatures in Tables 14 and 15 reveals a lower storage room temperature previous to November 13 in 1923 than in 1922, which is in conformity with the outdoor temperatures of the two seasons. Outdoor conditions were more favorable for a further decline in storage temperatures after November 13, 1923, but evidently the owners were not desirous of obtaining a storage room temperature below 36 to 40° F., as the average mean daily temperature maintained from November 13 to December 24 was slightly above 39° F.

Table 16 shows the temperatures recorded for a storage in Lenawee County in 1923-1924. The prevailing outdoor temperatures during late October and November were two or three degrees higher than for the Kent County storage (Table 15) during the same period, but a lower mean daily storage room temperature was maintained. The mean storage temperature was reduced from 49° F. on October 15 to 32° F. on October 31 and after the latter date was maintained below 40° F.

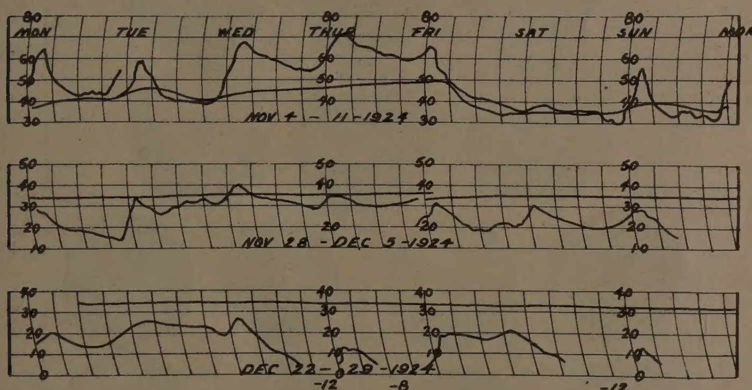


Fig. 5.—Outdoor and storage room temperatures recorded as storage E during three weeks of the season of 1924-1925. Same comment as for Figure 4.

except for four days during the middle portion of November. Incidentally, it should be mentioned that this was the first season of operation for this storage. Further experience in management would undoubtedly have given even more satisfactory storage temperatures than were recorded. This is evidenced by the fact that during the months of January and February the storage temperature was never permitted to go above 35° F. or below 31° F.

The later maturing winter varieties of apples were not harvested until the last two weeks of October in 1924 because of unfavorable weather during the late summer and early autumn. Table 17 shows that the outdoor minimum temperatures were at the freezing point or lower every night during the latter half of November. Consequently, conditions during the fall of 1924 were quite favorable for reducing the temperature of the apples to near the freezing point within a comparatively short time after harvest. In fact, there were only eight days

after the first of November when the mean storage room temperatures were 40° F. or higher.

The rather wide range of outdoor temperatures during late October and the early part of November, 1924, resulted in a mean daily storage temperature as much as ten degrees lower than the mean daily outdoor temperature. Even the average mean daily storage room temperature for the month of November was over two degrees lower than that for the outdoors, which is a condition better than can usually be attained. Further, but cautious ventilation, during late November would have

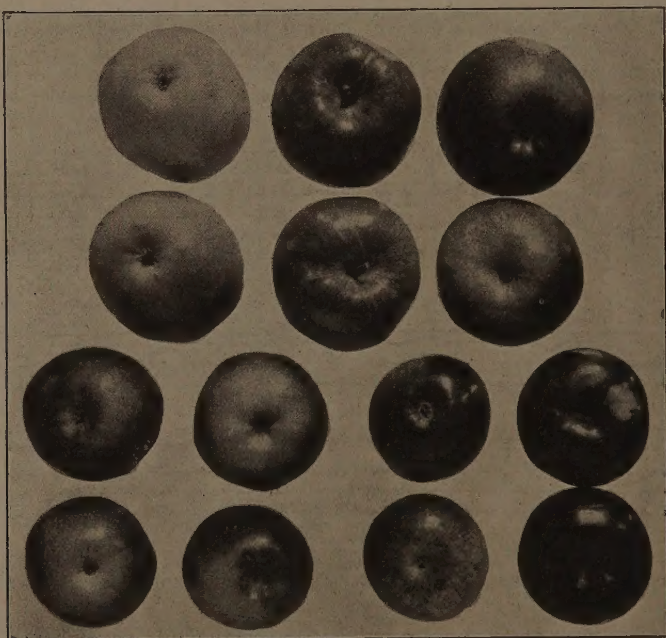

Fig. 6.—These apples were removed from storage A, near Grand Rapids, March 13, 1923, shipped to East Lansing and photographed March 16. The varieties are Winter Banana, Northern Spy, Baldwin, Steele Red, Jonathan, Fameuse and McIntosh. All were in merchantable condition.

resulted in still lower storage temperatures and a lower mean storage temperature.

The conclusions which may be drawn from a study of the temperature tables are (1) that storage temperatures, during the fall months tend to follow both the seasonal outdoor mean and minimum temperatures, (2) that usually there is only a slight variation in temperature in the storage room from night to day, (3) that the occasional wide variations recorded are probably due to the opening of the rooms for the introduction of additional apples, (4) that a mean storage tempera-

ture three to six degrees lower than the average mean daily outdoor temperature may be contemplated under good air-cooled storage management, (5) that storage temperatures not more than five degrees above the average daily minimum temperatures may be reasonably expected where good management prevails, and (6) that in Michigan, temperatures which will compare favorably with those maintained in cold storage warehouses cannot ordinarily be attained in air-cooled storage houses until late November or possibly the first week in December.

## DO APPLES KEEP IN COMMON STORAGE?

The question which frequently arises in the minds of fruit growers who have not had experience with air-cooled storage is "how can we hold our apples from picking time until the outdoor temperatures are sufficiently low to permit good storage temperatures in the air-cooled storage house?" During the first half of October, when most of the apples are ordinarily placed in storage, the temperatures of the air-cooled storage rooms are usually above 50° F. and occasionally as high as 60° F. In a preceding portion of this bulletin it was shown that high temperatures hasten ripening and that apples should be stored at approximately 32° F. immediately after picking if they are to be held for several months. A logical conclusion drawn from the two preceding statements would appear anything but favorable for air-cooled storages unless they are supplemented during the fall months with ice chambers or mechanical refrigeration. However, a practical and economical system of utilizing ice in an air-cooled storage has not been devised and mechanical refrigeration is expensive of installation and operation in small storages.

In 1917 Ramsey and Dennis (11) reported that apples held in good condition for several months in the air-cooled storage houses of the Pacific Northwest. Marble (9) found that apples stored in his cellar storage softened quickly but held throughout the storage season with little loss. Magness and Burroughs (7) working at the Marble storage found the cellar stored apples ripened as much in one month as apples stored at 32° F. did in four months. They further state, however, that the apples ripen until a certain point is reached and then remain in this state throughout the usual storage season. These apples are less resistant to rots and bruises than those which have been held at the usual cold storage temperature.

Detailed observations of apples of several varieties held in several Michigan air-cooled storages during the past three seasons have confirmed the reports of investigators in other states. In general, where apples suitable for cold storage purposes have been held in houses in which the management practices were fair or better, the amount of unmerchantable fruit found in late winter or early spring has not exceeded that which went into the storage at harvest time, except for that due to wilting. This loss is discussed later under the heading of "humidity."

Eight storages located in Oakland, Lenawee and Kent counties were visited March 10 to 14 inclusive in 1924; at most of the houses grading

operations were then in progress, thus affording an excellent opportunity to study losses due to improper storage conditions. In every case, but one, the losses which could be attributed to rots and other troubles, wilting excepted, developed while in storage were negligible. In this one instance the percentage of apples showing rots ran as high as 20 with certain varieties. The apples which went into this storage were from an orchard which had not been properly managed and but a small percentage of them were suitable for either common or cold storage. Furthermore, the storage management had been unsatisfactory during the winter months.

During the storage period of 1923-1924, the ground color on the Northern Spy had changed from the characteristic green at picking time to a light lemon and such varieties as Northern Spy, Baldwin and Steele Red were in prime, crisp eating condition. These apples were bringing the top market price for the variety, grade and locality at that season.

The results obtained on a small scale in the spring of 1923 are in line with those mentioned for the spring of 1924 and the owners of the older storages report similar results for each year of operation, so it would appear that 1923-1924 was not an unusual season in so far as final results obtained are concerned.

Figure 6 shows several varieties of apples which were taken from storage A March 13, 1923. The picture was taken after the apples had been removed from the storage three days, shipped by parcel post to East Lansing and photographed after being held at ordinary living room temperatures for a day after arrival.

Storage D was built with the intention of later equipping it with a circulating brine system of cooling which would be relied upon to cool the apples during the fall months, but after the experience of one season the owner was entirely satisfied with the results obtained without any supplementary equipment.

The evidence, then, gathered from Michigan air-cooled storage houses, as well as from those in a number of other states, shows that winter apples do soften and ripen materially during the fall months before the temperatures in the storages can be lowered to those approximating suitable cold storage temperatures, but that sound apples of varieties having good keeping qualities, remain in a good merchantable condition until early spring in properly managed air-cooled storage houses and cellars.

## THE CONSTRUCTION AND INSULATION OF THE STORAGE HOUSES

One of the primary requisites of an air-cooled storage is that it be sufficiently insulated to maintain a warehouse full of apples at rather even temperatures during periods of warm weather, without artificial cooling, or throughout a continued period of extremely cold weather without resorting to the use of heaters. The latter is the more important to bear in mind because a storage house that is sufficiently insulated to prevent freezing of the apples during a week of zero or lower temperatures will, if properly managed, give satisfaction during intervals of warm weather in the fall.

Numerous materials and combinations are used in storage house walls and ceilings. No one building material or combination of materials may be considered as the best for the many situations under which storages are erected and to meet the various requirements of individuals. For instance, some may be interested in converting an existing building into a storage; some prefer partly underground rooms while others want them above ground; some may emphasize the necessity of having a fire-proof building; some may wish to build a storage which is in harmony with other existing buildings in style of architecture, and others may have reason for using materials at hand or which are more easily available. In general, there are two courses open to the prospective builders; (1) to build a supporting wall which may have little insulation value and then line this wall with materials of high insulation values, or (2) to build a wall which will combine supporting strength and insulation value. The latter is usually the more economical course.

Heat may be transmitted by (1) conduction, (2) radiation, and (3) convection. If one end of an iron rod is in a fire, heat is transmitted toward the other end of the rod by conduction. Heat is in this way conducted through solid walls. The heat which is felt when one is standing near a hot stove illustrates transmission of heat by radiation. The principle of convection is illustrated in Figure 7; this circulation occurs when the air in one part of the air chamber or cell is warmer or cooler than that in another part. Heat is transmitted across the air spaces of walls in this manner. The transfer of heat through walls is chiefly due to convection and conduction.

The amount of heat transmitted by air circulation, or convection, depends on the difference in weight between a column of the warmer air and a like column of the colder air in the enclosed chamber, and these weights in turn depend on the difference in temperature between the coldest and warmest air in the enclosed chamber and on the height of the chamber. (See Figure 7.) Thus, small or shallow air chambers result in a slower transfer of heat than large or high ones. It is evident, then, that horizontal air spaces in walls result in a slower transmission of

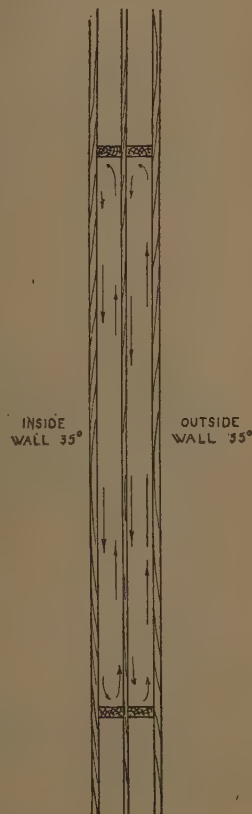


Fig. 7.—Illustrating heat transmission through hollow walls. The air in the right inclosed space, being heated by contact with the warmer boards, becomes lighter and rises; when it arrives at the top of the confined space, it passes down the right side of the middle board where it gives up its heat; as it is cooled, it contracts and becomes heavier, and sinks to the bottom of the inclosed space. In this manner, heat is transmitted from the outer board wall to the middle one, and in turn from the middle wall to the inner one.

heat by convection than vertical ones, and that the relatively high insulation values of granulated cork, packed mill shavings, packed mineral wool, hair-felt, etc., are in a large measure due to the numerous but tiny air cells contained in these materials. Still air, commonly referred to as "dead air," has a very high insulation value, but still air exists only under very exceptional conditions. The term "dead air space," as commonly used, refers to confined air and this is usually in circulation and thus may have a relatively low insulation value.

There is more or less conduction of heat through all solid bodies, but wide differences in conductivity exist in the various building materials. Water is a very good conductor, consequently, it is essential that any materials used for insulation purposes be kept as dry as possible. Mill shavings, and sawdust are of little value as insulation materials unless they are kiln-dried and maintained in this condition. Concrete, soft brick, unglazed tile and ordinary plaster absorb moisture and become less efficient insulators. For these reasons, waterproof paper (not building paper) should be generally and liberally used in all storage walls of frame construction.

From the above discussion the following conclusions may be drawn; loose material packed tightly to form a multitude of small air spaces or cells to result in a negligible circulation of air usually makes for efficient insulation; uninterrupted air spaces extending from the top to the bottom of a wall usually result in a constant circulation of air and inefficient insulation; horizontal air spaces, as in tile, are preferable to vertical; the walls must be kept dry at all times.

**Table 1. Relative Insulation Values of Some Common Building Materials.**

| MATERIAL | Thickness Inches | Relative Insulation Value |
|---|---|---|
| Corkboard | 1 | 100 |
| Brick | 8–10 | 60–90 |
| " | 13 | 70–110 |
| " | 16–20 | 100–165 |
| Brick Wall, Furred and Plastered | 9 | 140–150 |
| " " " " " | 13 | 160–180 |
| " " " " " | 18 | 180–215 |
| Brick, 4" Air Space, Brick, ¾" Plaster | 12½ (Solid Brick) | 150–160 |
| Concrete* or Stone | 12 | 40–60 |
| " " " | 16–20 | 55–100 |
| Hollow Tile with ½" plaster on each side (one air space) | 4 | 50–100 |
| Interlocking Tile | 13 | 130–145 |
| Mortar | 1 | 4 |
| Plaster | 2 | 40–45 |
| Thermocrete | 1 | 60–65 |
| Wood (Fir) | ⅞ | 30–35 |
| Dry Saw Dust | 1 | 50–65 |
| Dry Mill Shavings (Packed) | 1 | 70–80 |
| Boards 1", Air 10", Boards 13/16", Boards ⅝" | 12½ | 310–330 |
| Double 1" Boards each side of 10" Air Space | 14 | 525-540 |
| Lath and Plaster, Air, Double ⅞" Boards with Paper Between | | 155–180 |
| Packed Mineral Wool | 1 | 90 |
| Packed Granulated Cork | 1 | 90 |
| Hairfelt | 1 | 85 |
| Confined Air | 1 | 45 |

Table 1 is a compilation from various sources and is presented to show the approximate insulating values of some materials commonly

*The use of cinders instead of stone in the concrete mix increases the insulation value two to three times that given for concrete.

used in constructing the walls and ceilings of storage houses. Values above 100 indicate that the material has a correspondingly better insulation value than one inch of corkboard and those below 100 are relatively less efficient. In some cases the values given in the table represent the average range of values determined by several investigators working with materials of the same kind. They serve the purpose of a guide, however, in determining what materials to use and how thick the wall should be. Specific recommendations based upon experience in Michigan cannot be made at this time, but it is apparent that an insulation value of 200 or the equivalent of two inches of corkboard will provide ample insulation. Whether an insulation value of 150 is adequate remains to be demonstrated.

The details of wall and ceiling construction of a number of air-cooled storage houses in Michigan are listed in Table 2 and some of them are illustrated in Figures 10, 13, 15, 17, 18, 20 and 22. It will be

Fig. 8.—Storage A. See Table 2 for description and Figures 9 and 10 for details of construction. The depreciation of a house of this type is small.

noticed that no two of these storages have been built alike. A, B, D, E, F, G, K, L, N, O and R were originally built as air-cooled storage houses, while the others are remodeled portions of existing barns and other farm buildings. Of the buildings originally designed as storages three have walls of tile construction, five of concrete or concrete blocks and three are of frame construction. Each of the owners has indicated that he would again use essentially the same type of wall construction he now has, with minor changes in a few cases. Slight freezing has occurred in parts of two or three of the houses of frame and concrete construction but this has been due to the management rather than construction in at least one case.

The details of ceiling construction employed in the several storages varies considerably, but the tendency has been towards the use of two thicknesses of matched lumber with building paper between, used both above and below the joists, or equivalent materials. The owner of

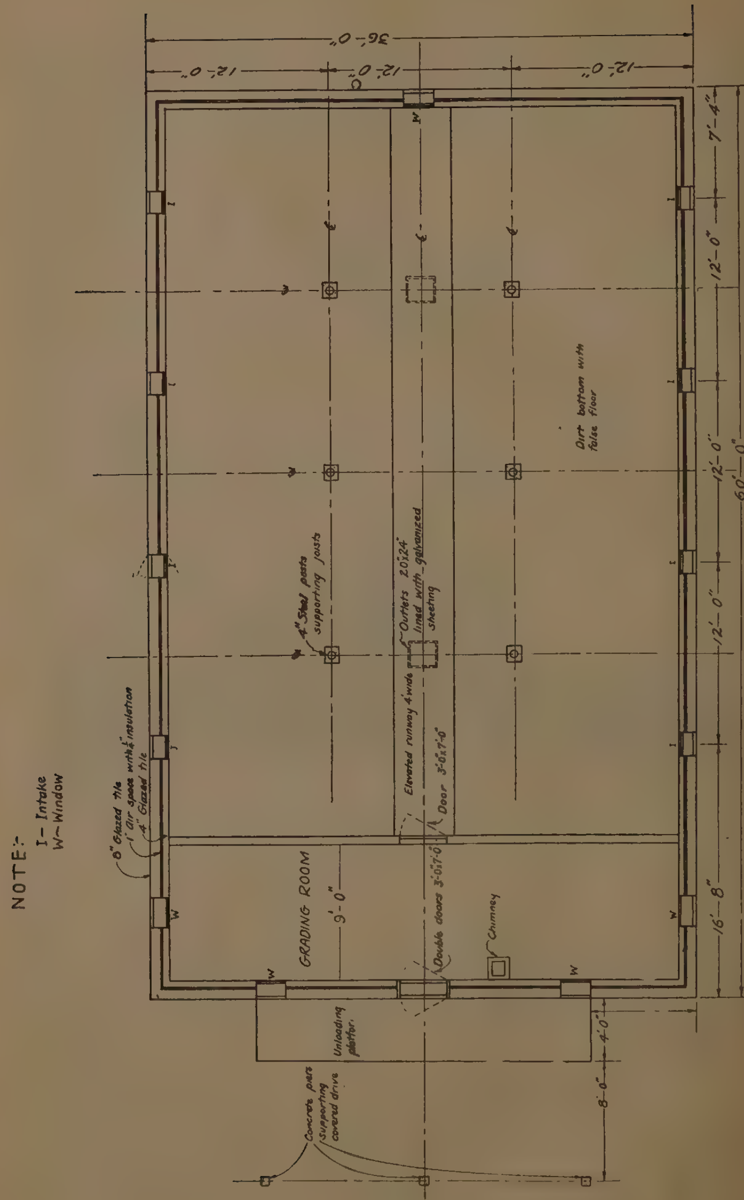


Fig. 9.—Floor plan of Storage A. Note the location of air inlets and air outlets.

storage D has stated that he should have used an inch of hair felt above the joists and the owner of storage G expects to supplement the present arrangement.

The walls of storages B, L, N, O and R and the remodeled buildings H, I, J, M and P are partly or entirely below ground and in these portions of the buildings concrete or stone have been used. Unless the monolithic concrete walls are thoroughly waterproofed on both the outside and inside, by applying one-half to three-fourths of an inch of 1:2 cement mortar, there may be a seepage of moisture through the walls which renders them of little value as insulators and may result

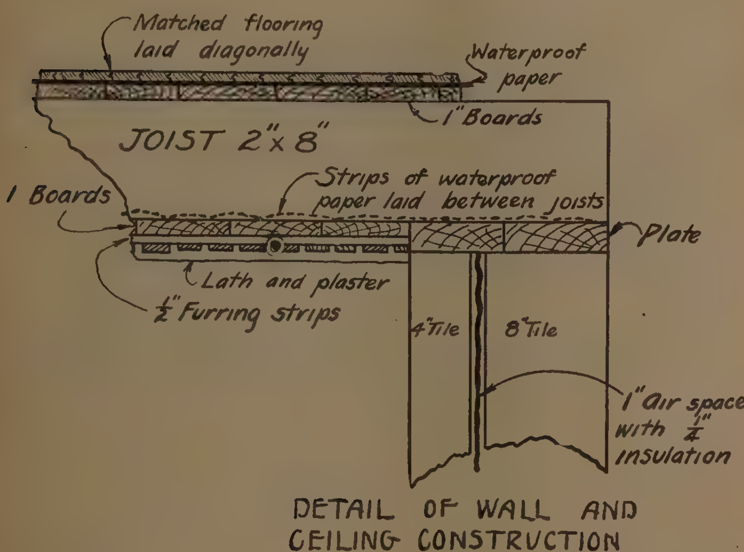


Fig. 10.—Storage A. There has been no loss from freezing in this storage during the ten years of operation.

in the accumulation of water on the floors of cellars located on heavy soils. Such a condition existed in storage L in 1923-1924.

In planning a storage it is well to safeguard the walls and ceilings against rodent infestation, fires, and warping and rotting of lumber due to high humidity. Therefore, the less lumber employed in the building of a storage, the more satisfaction it will give in these respects. The owners of storages A and E have nicely safeguarded themselves in these respects. For instance, the only wood exposed in the storage room of building A is that contained in the doors and door frames, while in E the only exposed wood consists of that making up the doors and their frames, and the posts and beams which support the ceiling.

## The Construction of Doors and Windows

The doors of a storage, including the covering for air intakes and outlets, must be well insulated and should be made to fit tightly. They may be made by alternating matched lumber and waterproof paper, using three or four thicknesses of the boards. A more commonly used method of making doors is illustrated in Figure 11. The space between

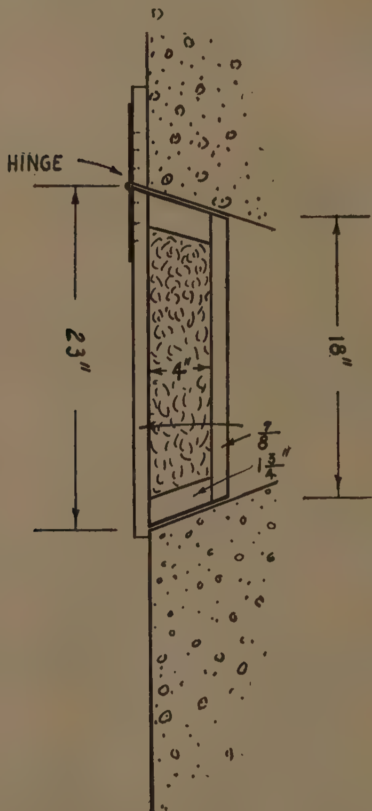


Fig. 11.—Illustrating one way in which doors for cold air intakes may be constructed. The four-inch space is filled with hair felt trimmings, finely ground cinders, oiled shavings or other materials of equal insulating value. Entrance doors may be built in the same manner.

the outer and inner boards of such a door should be at least four inches. This space may be filled with trimmings from hair felt, oiled shavings, crushed cinders, "thermocrete" (a gypsum product) or similar materials.

The doors may be made to fit tightly if the edges are beveled to

an angle of about 25 to 30 degrees and the door frames beveled in like manner. Then if they do not fit snugly on all sides, canvas belting six to eight inches in width may be nailed to the beveled door frames.

Where electric light is available there is no necessity for windows and since they make the problem of insulation more difficult, their number should be reduced to a minimum where electric light cannot be had. Windows should have double or preferably triple sash, or a single sash with an outer door made of two thicknesses of matched boards with waterproof paper between them.


Fig. 12.—Storage B. See Table 2 for description. The forcing of air through an underground tile by means of a fan and releasing the warm air through the small ventilator at A was discontinued in 1923, when the larger ventilator at B was constructed and the large front door was made to serve as the only air intake. The later results were much better.

## TEMPERATURES MAINTAINED IN COMMON STORAGES IN WINTER

Tables 14 to 17 (see appendix) show the temperatures that may be obtained in well constructed air-cooled storages. Both storages are entirely above ground. The walls of storage A consist of an outer wall of eight-inch glazed hollow tile with the air spaces running horizontally, an inch air space in which is placed a seaweed quilt of one-fourth inch thickness, and an inner wall of four-inch glazed hollow tile. A detailed description of this storage may be found in the Michigan Experiment Station Quarterly Bulletin for August, 1923 (10). The walls of storage E consist of twelve inches of interlocking tile with waterproof plaster on either side.

The average daily range or fluctuation of outdoor temperatures for the 15 days recorded in December, 1922, near storage A (Table 14)

was 14.7 degrees, but in the storage it was about one-half of one degree, and the greatest range of inside temperature for one day was one and one-half degrees. During January, 1923, the outdoor daily range was 11.1 degrees while it was slightly less than one-third of a degree in the storage. Furthermore, during this month the minimum storage temperature was 35° F. and the maximum only two degrees higher, while there were only ten days when the maximum outdoor temperatures was above freezing. From February 14 to 18 inclusive,

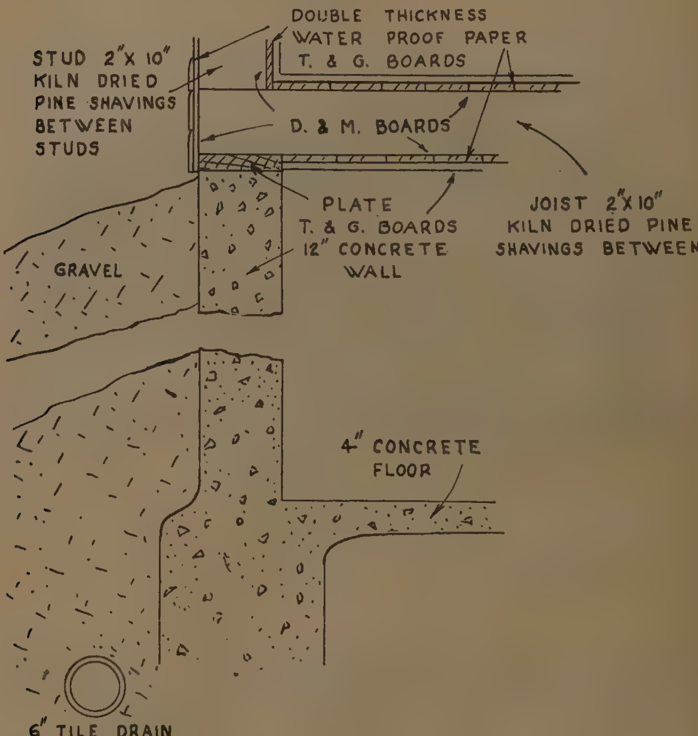


Fig. 13.—Illustrating the details of construction of Storage B.

the outdoor temperature ranged from 16 to 2° F. but the storage temperature dropped only two degrees during this period.

The temperatures were not recorded after December 24 for storage A in 1923 (Table 15), and up to this time there were only two nights when the outdoor temperature dropped below 20° F. However, there were only five nights after November 20 when the outdoor temperatures did not reach the freezing point or lower and during the period the storage temperature did not go lower than 35° F. It should be stated

that the storage temperatures were held 3 or 4 degrees higher during this period than was necessary or advisable.

During January, 1924, there were ten nights when the cutdoor temperatures at Storage E (Table 16) were 10° F. or lower and on five of these nights the thermometer dropped to —6 to —12° F., but the storage temperatures were maintained between 30 and 35° F., the lower temperature being recorded on only one night. The average daily range of outdoor temperatures was 17.6 degrees while that for the storage room was two-thirds of one degree. The average mean daily outdoor temperature for February was slightly lower than for January although there were only two nights with outdoor temperatures lower than 10° F. During this month the storage temperatures were held at

Fig. 14.—Storage D. See Table 2 for description. Since this storage was built in 1922, the owner has sold all of his winter apples undelivered—the buyers come to the storage and bring their own containers.

from 32 to 35° F., with an average daily range of less than one-half of one degree.

The outdoor and storage temperatures as recorded during several of the colder winter weeks of 1923 to 1924 are shown in Figures 2 to 5.

Temperature records were also attempted for storages D, F and H but the thermographs were in operation so irregularly that the records are not included in this report. Had the records for D and F been complete, they would probably have shown essentially the same results as those just discussed. Storage H is located in one corner of a barn basement and has only a ten-inch concrete block wall on two sides, so that it was necessary to use oil stoves in the storage room on a few occasions, during January and February, 1924, to prevent freezing of the fruit.

## Summary of Storage Insulation

A few concise statements with regard to the insulation of air-cooled storages may be ventured to summarize the foregoing rather lengthy discussion, although it should be stated that but few hard and fast rules may be formulated. Generally speaking, small but numerous air cells in a building material indicate good insulation value provided the material is kept dry. Large air chambers, such as those existing between the studs of frame buildings should be divided into a number

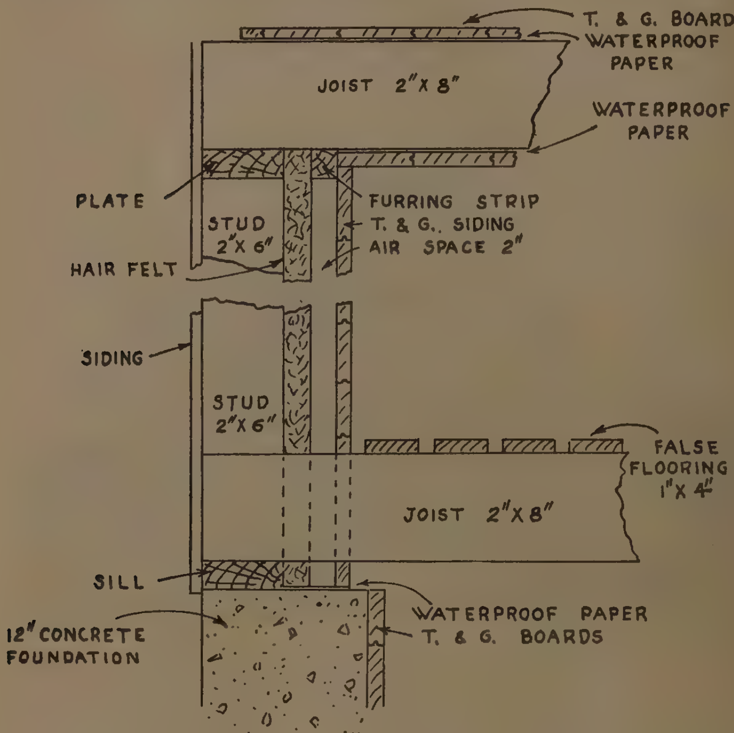


Fig. 15.—Illustrating the details of construction of Storage D.

of compartments with heights not exceeding three or four feet. The air spaces of tile and concrete blocks should be sealed with mortar at frequent intervals so as to prevent continuous air spaces. Since ordinary mortar is a good conductor of heat, straight, uninterrupted mortar joints are not desirable. Concrete and unglazed tile walls should be plastered with 1:2 cement mortar on both sides to waterproof them thoroughly. Boards are subject to warping and molding when exposed to the interior of storage rooms; hence, their use on the interior of the walls and ceilings should be reduced to a minimum. The doors should

be well insulated and fit tightly. Windows should seldom be installed, even though electric light is not available. The average daily range of fluctuation of temperature in a well constructed and well managed air-cooled storage should not exceed one-half of one degree after the temperature of a room filled with apples has been reduced to 35° F. A room with 10,000 bushels of fruit will have a lower average daily range of temperature than one with 5,000 bushels, other factors being equal. Temperatures of 32 to 35° F. may be safely maintained in well constructed storages regardless of outdoor weather conditions provided the storage is nearly full of fruit.

## THE VENTILATION OF THE STORAGE

The primary purpose of ventilation in the air-cooled storage is to regulate temperature and prevent excessive humidity. Several investigators have shown that ventilation also aids in controlling apple scald

Fig. 16.—Storage E. See Table 2 for description. This permanent type building is used exclusively for storage purposes.

by preventing the accumulation of certain gases about the fruits. Ventilation plays no part, however, in influencing the ripening of apples according to Magness and Burroughs (7) and furthermore, Magness (6) states that it gives no improvement of aroma or flavor.

Ventilation is accomplished by admitting cool air into the storage room through several openings located at or near the ground line, on two to four sides of the building and then permitting the warmer air of the storage room to pass out through ventilators extending from the ceiling of the storage room through the roof. The principle is illustrated in Figure 1. The purpose of having a number of air intakes is

to distribute the incoming air through the storage and thus bring it in contact with the maximum amount of fruit.

The underground tile intakes of the older storage cellars were largely for the purposes of giving a continuous supply of fresh air thus preventing the accumulation of gases and odors resulting from the ripening processes and decay of the fruits and to maintain more satisfactory humidity conditions. With respect to their value as an aid in cooling the fruit, Cotton and Faxon (5) state that nothing is gained in conducting air through long underground tile because the soil is warmer than the outdoor air in the fall, and Baker (1) says that the advantages of underground tile intakes are over-estimated. Furthermore, observations in Michigan have shown that, even where the flow of air through an underground tile is accelerated by the use of a fan the amount of air passing through the storage room is not sufficient to give the desired changes in storage temperatures.

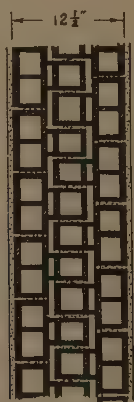


Fig. 17.—Detail of wall construction of Storage E. There are five horizontal air spaces between the two sides of the wall. Water proof plaster covers each side of the wall.

The cold air intakes for cellar or basement storages may be window-like openings just above the outside ground line. For the above ground storages the air intakes should be located as near the ground line as is practicable. If the storage is located on sloping land it is preferable to have the intakes located at a rather constant distance from the ground line as in Storage E rather than on a horizontal line as in storage G. These window-like openings should run horizontally rather than vertically. They should be fitted with insulated doors hinged at the top and opening outwards or with plugs. To prevent the entrance of rodents and other animals, one-fourth inch mesh wire screen may be installed in the openings. The intakes should be spaced at regular intervals on all sides of the building, possibly excepting the end of the building where the entrance door may be located.

The bottom of the outlet flue should be flush with the ceiling of the storage room and should be fitted with doors which are sufficiently

insulated to prevent the entrance of frost into the storage room, and can be easily opened or closed. The flues should be straight and the inner sides should be smooth so as to facilitate the movement of air. The sides should be sufficiently insulated and tight enough to prevent attic or second story room conditions from influencing the air movement in the flue. Two thicknesses of boards with waterproof paper between them usually provide the necessary insulation and if the inner course of boards is made to run vertically, there is less friction to retard air movement.

The upper outlet of the flue should be above the ridge of the roof, and furthermore, it should be above the tops of any nearby building so that a good "draft" may result. The top of the flue should be roofed sufficiently to keep out rain and snow. It should be open on all sides but one-fourth inch mesh wire screen, or similar material, may be used to keep out birds. Draft-inducing cowls are sometimes used, but the cost of cowls large enough for ventilating flues of the sizes ordinarily used in air-cooled storages is rather high.

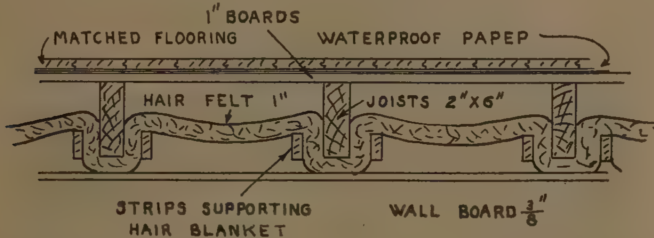


Fig. 18.—Detail of ceiling construction of Storage E.

## Motor Driven Fans as an Aid in Ventilation

None of the storages now in operation in Michigan is equipped with motor driven fans to accelerate the movement of air through the storage room. There is no question but what they will increase the volume of air movement through the room but the cost of installing and operating them is very high compared to the cost of increasing the number and size of air intakes and outlets sufficiently to produce the same volume of air movement. Cotton and Faxon (5) state that a few Ohio storages are equipped with electric fans to exhaust the air but they do not recommend them. They found that ordinary ventilator flues worked satisfactorily in a three-mile breeze and that they usually have at least that much wind velocity on nights that are cool enough to warrant opening the ventilators.

## False Floors as an Aid in Ventilation

Storages D and F are equipped with permanent false floors similar to the one shown in Figures 1 and 15. They are usually constructed by laying three or four inch boards slightly less than an inch apart on joists, the tops of the latter being a few inches higher than the tops of the cool air intakes. This permits a free circulation of air under

the false floor and a more even distribution of the cool air through the stacks of fruit. They also enable one to take better advantage of strong winds by opening the intakes only on the windward side of the storage, thus forcing the incoming air to pass up through the fruit and out the ventilating flues rather than passing out the intakes on the leeward side of the building.

Theoretically, false floors should result in a freer and better distributed movement of air through the storage room and hence quicker and more uniform cooling of the fruit. Investigations, however, conducted up to the time of this writing have not proven that the results are more satisfactory in storages having permanent false floors than in those in which pieces of rough lumber are laid over poles or timbers four to six inches thick which in turn are laid upon the floor of the storage room. Furthermore, the latter method of permitting the air to circulate underneath the fruit renders a greater volume of the storage room available for the stacking of the fruit, or in other words,

Fig. 19.—Storage F.—See Table 2 for description.

increases the storage capacity without increasing the cost of construction. The permanent false floor, then, may possess certain advantages, but it is doubtful if the advantages compensate for the additional cost of construction and the amount of space in the building which is rendered unavailable for stacking fruit.

**Size and Number of Air Intakes and Outlets**

The ventilation system of the storage house is second only to insulation in importance, because the rapidity of cooling during the fall months is closely related to the volume or amount of cool air which is made to come in contact with the warmer apples. Yet, there is no storage problem upon which there are available so few concrete facts and upon which investigators express such varied, but specific judgment.

Ramsey and Dennis (11) state that the difference in air pressure induced by differences in temperature are so slight that air circulation

is easily checked if the passages are small or crooked; they should be of liberal size, straight and direct. They recommend that intakes with a minmum size of 18″ x 24″ be placed every ten feet about the sides and ends of the building, and that there should be one outlet flue for each 20 feet of storage room length. Cotton and Faxon (5) do not specify the amount of air intake or outlet area but contend that the ratio of air intake area to outlet should be as 10 is to 6.5. Cole (4) believes that there should be one square foot of air intake for each 700 cubic feet of storage space, that the minimum size of these intakes should be 18″ x 30″ and that they should be located on at least three sides of the storage.

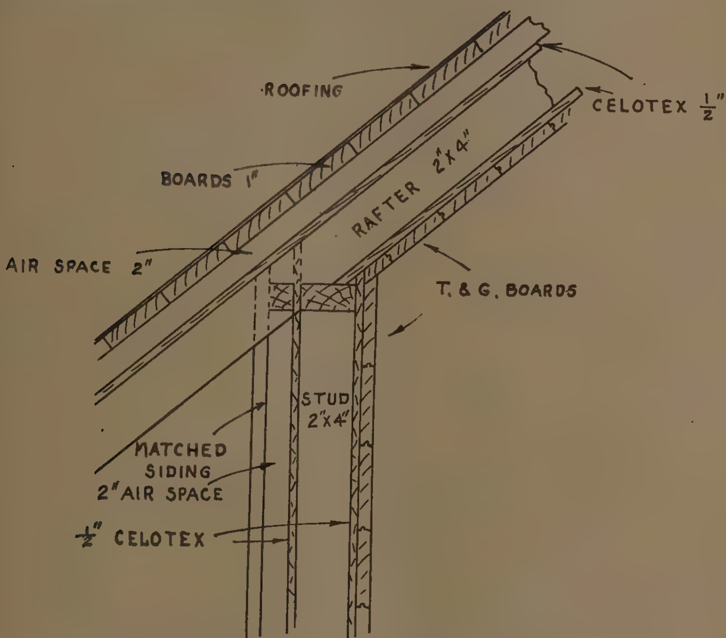


Fig. 20.—Detail of wall and ceiling construction of Storage F.

The combined cross-section area of the outlet flues should nearly equal that of the intakes, in his opinion, although he states that if the flues are high the outlet area may be reduced to two-thirds or even one-half of the intake area.

It has been calculated by Magness (6) that a volume of air 1,000 times the volume of the apples is necessary to cool apples from 60° to 50° F. if the air is entering the storage room at 40° F. and leaving at 50° F. He recommends that the combined area of the air intakes should amount to at least one per cent of the total floor area of the storage, or preferably more, and that the combined area of the outlets be fully one-half that of the intakes. In a letter (Jan. 30, 1925) he states that he would

**Table 2. Showing Size and Details of Construction**

| Storage | Built | Dimensions (Room) | Capacity (Bu.) | Wall Construction (Read from outside to inside) | Ceiling Construction (Read from top to bottom) | Floor | Doors |
|---|---|---|---|---|---|---|---|
| A | 1914 | 34'x48'x12' | 8000 | 8" glazed tile, 1" air with ¼" quilt, 4" glazed tile. | Boards, paper, boards, 10" air, paper, boards, ½" air, waterproof plaster. | Dirt | 1-6' 8"x3'3" |
| B | 1916 | 16'x38'x10' 6" | 2100 | 12½" concrete water-proofed. | Boards, paper, boards, 10" mill shavings, boards, paper, boards. | Concrete | 1-5"x7" |
| C | 1922 | 38'x30'x13' | 6000 | Boards, paper, 6" concrete, 12" tile, ½" air, 4" tile. | Hay (several feet), boards, paper, 12" air, boards. | Dirt | 1-6"x7" |
| D | 1922 | 38'x58'x11' 8" | 10000 | Boards, 2" air, 2" hair felt, 6" air, boards. | Boards, paper, 8" air, paper, boards. | Concrete | 1-4'x6' |
| E | 1923 | 31'x78'x12' 6" | 12000 | Plaster, 12" interlocking tile, plaster. | Boards, paper, boards, air 3", 1" hair felt, air 2", wall board. | Dirt | 1-6'x6'<br>1-3'x6' |
| F | 1923 | 24'x36'x12' | 5000 | Boards, 2" air, ½" celotex, 4" air, ½" celotex, boards. | Roofing, boards, 2" air, ½" celotex, 4" air, ½" celotex, boards. | Dirt | 1-4'x6' 3"<br>1-2'x3' |
| G | 1923 | 33'x51'x12' | 8000 | 8" concrete blocks, 2" air, 6" concrete blocks. | Boards, 6" air, boards. | Dirt | 1-3' 6"x6' |
| H | 1923 | 22'x38'x8' | 2600 | 10" concrete blocks. | Plank, 12" air, paper, boards. | Concrete | 1-4'x6' |
| I | | 22'x33'x7' 6"<br>22'x25'x7' 6" | 3800 | 8" concrete blocks. | Boards, boards. | Boards | 1-6'x6' |
| J | 1923 | 36'x80'x9' | 11000 | 18" stone masonry. | Boards, paper, boards, 10" air, ½" celotex, boards. | Dirt | 1-6'x7'<br>1-3'x6' |
| K | 1923 | 35'x56'x14' | 11000 | 8" glazed tile, 2" air, 8" glazed tile. | Boards, paper, boards, 10" air, sheetrock. | Dirt | 2-3' 10"x6' 6" |
| L | 1923 | 28'x48'x12' | 6500 | 12" concrete. | Boards, paper, 10" air, paper, boards. | Dirt | 1-8'x8' |
| M | | 30'x80'x9' | 8000 | 8" concrete block. | Boards, paper, boards. | Concrete | 1-7'x8' |
| N | 1923 | 32'x42'x7'<br>32'x43'x9' | 7000 | 24" concrete, (basement). Boards, paper, sheeting, paper, 6" sawdust, boards. | Boards, 8" sawdust, boards, 8" sawdust, paper, boards. | Dirt | 2-3' 10"x6'<br>1-8'x9' |
| O | 1924 | 45'x90'x9' | 14000 | 16" concrete (below ground), 12" tile (above ground). | Boards, paper, boards, 12" air, plaster, ½" air, plaster. | Sand | 0 |
| P | 1890(R) | 15'x27'x7' | 1000 | 18" Stone. | Boards, 8" air, boards, plaster. | Dirt | 1-3'x6' |
| Q | 1924 | 36'x28'x9' | 3500 | 8" brick, 4" mill shavings, 8" concrete block, asphalt paint. | Boards, paper, boards, 8" shavings, sheeting lath, plaster. | Sand | 1-4'x6' 6" |
| R | 1924 | 29'x67'x8' 8" | 6500 | 8" concrete, 4" air, 8" concrete. | Boards, ¼" quilt, 4" air, 6" sawdust, insulated paper boards. | Dirt | 0 |

**of Some Air-Cooled Storage Houses in Michigan.**

| Windows | Air Intakes | Air Outlets | Container | Cost | Remarks |
|---|---|---|---|---|---|
| 1-4′ 8″x2′ | 8-18″x 30″ | 2-24″x24″ | Crates | $2000 | 9′ Sorting room across one end. Storage for container on second floor. |
| 0 | 0 | 2-24″x24″ | Crates, baskets | | Partly underground. Sorting room on second floor. |
| 1-26″x34″ | 4-24″x24″ | 4-15″ diam. | Bins | 1000 & labor | This room was built in one end of a frame barn. |
| 0 | 6-18″x30″ 2-24″x36″ | 3-18″x18″ Revolving ventilator | Barrels | 4000 | A false floor is constructed 4′ above the concrete floor. Sorting room across one end of building. Storage for for containers on second floor. |
| 0 | 12-16″x2′ 8″ | 2-48″x48″ | Crates | 5000 | Used only for storage. |
| | 4-16″x28″ | 2-16″x28″ | Bins | 1600 | False floor. Used only for storage. |
| 0 | 10-18″x30″ | 3-24″x24″ | Bins, baskets | 2000 | Used only for storage. |
| 3-2′ 9″x3′ 7″ | 0 | 0 | Crates | | Part of barn basement partitioned off for storage. Partly underground. |
| 0 | 2-10″x36″ 2-18″x24″ 3-24″x30″ | 1-36″x48″ | Crates, bins | | Barn and fruit handling rooms above storage. Partly underground. Remodeled 1923. |
| 0 | 11-18″x36″ | 2-42″x42″ | Crates, bins | | Remodeled basement of 50 year-old-barn. Partly underground. |
| 0 | 10-19″x36″ | 2-42″x42″ | Crates | | Sorting room across one end. Storage for containers on second floor. |
| 0 | 2-8″x20″ | 2-24″x24″ | Bins | | Partly underground. |
| 6-30″x30″ | 0 | 0 | Crates, bins | | Partly underground. Machinery on second floor. |
| 4-24″x48″ | 6-10″ diam. 4-12″x22″ 13-8″x24″ 10-8″x14″ | 2-21″x25″ 4-21″x25″ | Crates, bins | 3000 | Basement and ground floor used as storage. Upper line data relate to basement; lower to ground floor. |
| 0 | 14-18″x30″ | 2-48″x72″ | Crates | | Partly underground. Ground floor used for grading and packing. Second floor for containers. 12000 bu. potato storage adjoins apple room. |
| 2-15″x30″ | 1-6″ diam. | 1-6″ diam. | Crates | | Underground storage. Tool house above storage room |
| 0 | 8-25″x26″ | 3-20″x35″ | Crates | | Remodeled from old canning factory. Full second story for containers. |
| 6-15″x30″ | 5-21″x36″ | 1-54″x72″ | Barrels | 4200 | Partly below ground. Packing room on ground floor. |

be inclined to say two per cent rather than one, if making the preceding statement today.

In each of the above cases emphasis has been placed on the necessity of securing the passage of a large volume of air through the stacks of fruit in the storage room, but when the recommendations are reduced

Fig. 21.—Storage G. See Table 2 for description.

to a common basis they are not in agreement as to the minimum size or total area of openings that should be specified for a storage room of some given size.

Table 3 is evidence that the rate of air flow through an outlet flue depends on the height of that flue. These data indicate that the rate of air flow through a flue of a specified size would be approximately 50 per cent greater if the flue extended through a second story, as in the cases of storages A, D, K, O and R, than would be the case were there no second story, as in the cases of storages E and G. Thus, the combined area of outlet flues need not be as large where there is a full second story as in other cases.

**Table 3. Effect of Height of Outlet Flue on Volume of Air Discharged. Five Degrees Difference in Temperature. After R. C. Carpenter (3).**

| Height of Flue, Ft. | Cu. Ft. Air Discharged per Minute |
|---|---|
| 1 | 24 |
| 5 | 55 |
| 10 | 77 |
| 15 | 94 |
| 20 | 108 |
| 30 | 133 |
| 40 | 153 |

## Rate and Quantity of Air Flow Through the Storage Room

Many tests have been conducted during the past two storage seasons to determine the rate of air movement through air-cooled storages, when operated under various sets of conditions, with the hope of obtain-

ing some information that would serve as a basis for future recommendations in designing and operating storage houses. For the purpose of obtaining these measurements, sensitive wind-recording instruments were stationed near the centers of the bases of air outlet flues. The number of cubic feet of air passing through the flue in an hour was then calculated, assuming the rate of movement through the several parts of the outlet to be uniform. A few tests showed that a crate of tree run apples displaces about one-half cubic foot of air. Knowing the dimensions of the storage room, the number of crates of fruit in the room, and the volume of air movement through the outlet flues, it is

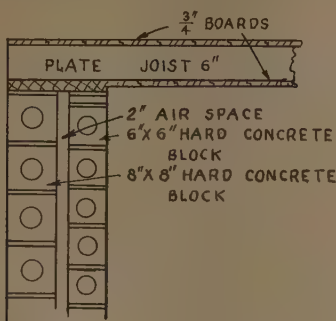


Fig. 22.—Detail of wall and ceiling construction of Storage G.

possible to determine the number of times the air is changed in the room during an hour.

It is admitted that this method of attempting to measure the air movement through a room is not accurate, but it does show the relative amounts of air movement under the different sets of conditions and thus serves the purposes for which the measurements were intended. The method is inaccurate in that the velocity of the air was measured in the center of the lower end of the flue, while Table 4 shows that air movements are slower in the corners and near the edges of the flue.

**Table 4. Rate of Air Movement Through Different Parts of an Outlet Flue. Inside Dimensions of Flue 4 ft. x 4 ft. 6 in., Height 10 Feet. Outside Wind Velocity About 15 Miles per Hour.**

| Location | Velocity (ft. per min.) |
|---|---|
| Base of Outlet—Center | 370 |
| " " " Edge | 207 |
| " " " Corner | 175 |
| Mid-Height of Outlet—Center | 445 |
| " " " " Edge | 197 |
| " " " " Corner | 165 |
| " " " " 6" from side | 261 |

This table further indicates that the contention that a square outlet is valuable only to the extent of the enclosed circle is not well founded. To obtain further information in this regard, a volume of smoke was

released in this storage. The smoke entered every portion of the area of the outlet flue, although the rate of entrance was much slower about the edge of the flue than in the central portion. Furthermore, the velocity of the smoke rising through the center of the flue was accelerated after it passed the basal part and that rising along the edges was retarded and diverted toward the center, thus substantiating the velocities recorded by the instruments. These facts are in themselves good arguments for outlets of large size.

An effort has been made to simplify the several tables which relate to the rate of air movement through storage rooms. Thus only such data as seem absolutely essential to the point in hand are included in the tables. The tests, for comparison with one another, are grouped and each group is assigned a Roman numeral. It may, therefore, be assumed that the tests within one group were conducted under identical conditions except for such differences as appear in the tables.

Table 5 is designed to show the effect of varying the size of a single outlet flue on the velocity and volume of air movement through the storage room*. With the exception of the test in Group I, decreasing the size of the outlet has increased the velocity of air movement through the flue. In every case, decreasing the size of the outlet has materially decreased the volume of air moving through the storage, as indicated by the number of times the air was changed in the storage in an hour. The decrease in the quantity of movement has not been in proportion to the size of the outlet, but halving the size of the outlet has, on the average, reduced the quantity of air movement about 35 per cent.

**Table 5. Effect of Size of Outlet Upon Rate and Quantity of Air Flow.**

| Group | Test No. | Area of Outlet (sq. ft.) | Velocity of Air Movement (Ft. per hr.) | Quantity of Air Movement (No. of air changes in room per hr.) |
|---|---|---|---|---|
| I | E 10 | 12.5 | 8650 | 3.86 |
| | E 11 | 7.6 | 7425 | 2.02 |
| | E 12 | 6.25 | 6375 | 1.42 |
| II | E 14 | 6.25 | 10350 | 2.31 |
| | E 15 | 3.8 | 11350 | 1.54 |
| III | E 17 | 12.5 | 10400 | 4.64 |
| | E 19 | 6.25 | 15480 | 3.48 |
| | E 20 | 3.12 | 19500 | 2.18 |
| IV | E 22 | 12.5 | 7850 | 3.17 |
| | E 24 | 6.25 | 13250 | 2.95 |

Table 6 shows that it is preferable from the standpoint of volume of air movement, to use two outlets, each of which has an area of 6.25 square feet, rather than one outlet with an area of 12.5 square feet. These results are in conformity to those reported in the preceding para-

*The area of the outlet flue was reduced at the lower end, the flue being of full size above this point. It may be questioned, therefore, whether reduction throughout the length of the flue would give essentially the same results. The rates of air flow through flues of different sizes in storages of approximately the same size indicate that the method used in these tests (when the flues were not more than 10 feet high) is satisfactory for rough comparisons even though it may be technically inaccurate.

graph, in which it was shown that halving the size of the outlet did not reduce the air movement to one-half.

**Table 6. Comparison of the Use of the Same Total Outlet Area in One and Two Ventilatng Flues.**

| Group | Test No. | No. Outlets | Velocity of Air Movement (Ft. per hr.) | Quantity of Air Movement (No. of air changes in room per hr.) |
|---|---|---|---|---|
| V | E 17 | 1 | 10400 | 4.64 |
| | E 18 | 2 | 13200 | 5.9 |
| VI | E 22 | 1 | 7850 | 3.17 |
| | E 23 | 2 | 10950 | 4.9 |

Table 7 is arranged to show the effect of number of outlets in operation upon the velocity and volume of air movement through the storage room. The results indicate that the volume of air passing through the house is directly proportional to the number of air outlets employed. The tests within each group were usually made within an hour of each other, but even then the constantly varying velocity of the outdoor winds may have been sufficient to account for such departures from the preceding statement as exist in some of the groups.

**Table 7. Effect of Number of Outlets of Same Dimensions on Rate and Quantity of Air Flow.**

| Group | Test No. | No. Outlets | Total Area of Outlets (Ft.) | Velocity of Air Movement. (Ft. per hour.) | Quantity of Air Movement. (No. air changes in room per hr.) |
|---|---|---|---|---|---|
| VII | A 1 | 2 | 8.0 | 39600 | 19.19 |
| | A 2 | 1 | 4.0 | 30300 | 7.34 |
| VIII | D 3 | 3 | 7.6 | 33600 | 11.63 |
| | D 6 | 1 | 2.2 | 27450 | 2.75 |
| IX | E 16 | 2 | 25.0 | 10650 | 9.5 |
| | E 17 | 1 | 12.5 | 10400 | 4.64 |
| X | E 18 | 2 | 12.5 | 13200 | 5.9 |
| | E 19 | 1 | 6.25 | 15480 | 3.48 |
| XI | E 21 | 2 | 25.0 | 6700 | 6. |
| | E 22 | 1 | 12.5 | 7850 | 3.17 |
| XII | E 23 | 2 | 12.5 | 10950 | 4.9 |
| | E 24 | 1 | 6.25 | 13250 | 2.95 |
| XIII | F 2 | 2 | 6.2 | 10250 | 6.71 |
| | F 1 | 1 | 3.1 | 10200 | 3.24 |

Beaver boards were cut to fit into the cool air intakes of storage E in such a manner as to reduce the area of each of ten openings to approximately one-half of the full area. The effect of so reducing the size of these openings as measured by the air flow through one of the outlets is shown in Table 8. Reducing the size of each intake to one-half its constructed size resulted in a material decrease in the velocity of air movement through the air outlets and a corresponding decrease in the volume of movement. When the outlets were opened to their full capacity, the increase in quantity of movement with the full size intakes was

about 60 per cent, but as the air outlet area was decreased, the differences in velocities and quantity of air flow were less pronounced, indicating that large intakes do not result in a corresponding increase in air movement unless the outlets are also of sufficient size readily to permit the exit of the full capacity of the intakes.

**Table 8. Effect of Size of Intakes on Rate and Quantity of Air Movement.**

| Group | Test No. | Size of Intakes (In.) | Area of Outlets. (Sq. ft.) | Velocity of Air Movement. (Ft. per hr.) | Quantity of Air Movement. (No. of air changes in room per hr.) |
|---|---|---|---|---|---|
| XIV | E 16 | 20 x 30 | 25 | 10650 | 9.5 |
| | E 21 | 15 x 20 | 25 | 6700 | 6. |
| XV | E 17 | 20 x 30 | 12.5 | 10400 | 4.64 |
| | E 22 | 15 x 20 | 12.5 | 7850 | 3.17 |
| XVI | E 18 | 20 x 30 | 12.5 | 13200 | 5.9 |
| | E 23 | 15 x 20 | 12.5 | 10950 | 4.9 |
| XVII | E 19 | 20 x 30 | 6.25 | 15480 | 3.48 |
| | E 24 | 15 x 20 | 6.25 | 13250 | 2.95 |

Several tests conducted for the purpose of determining the effect of increasing or decreasing the number of air intakes were found, upon analysis of the conditions under which they were conducted, to be unsatisfactory for comparison. The direction of the outdoor wind, the amounts of fruit and methods of stacking it near certain intakes, and other factors influenced the results more than was anticipated at the time the tests were made. Some of these factors will be discussed in a later portion of this bulletin as management practices. Doors, however, serve as intakes for cool air and Table 9 shows the resulting increase in air movement in the storages due to increasing the intake

**Table 9. Comparison of Combined Area of Intakes on Quantity of Air Movement.**

| Group | Test No | Total Intake Area. (Sq. ft.) | Quantity of Air Movement. (No. air changes in room per hr.) |
|---|---|---|---|
| XVIII | D 5 | 60 | 2.75 |
| | D 6 | 36 | 2. |
| XIX | E 2 | 96 | 8.39 |
| | E 3 | 42 | 4.69 |
| XX | F 1 | 43 | 3.24 |
| | F 4 | 9 | 1.1 |
| XXI | F 2 | 43 | 6.71 |
| | F 3 | 12 | 3.95 |

areas by opening the entrance doors. The upper test in each group was made with the doors as well as the intakes open, while the second line in each group gives the results when only the intakes were open. The difference between the total intake areas given in each group, excepting Group XX, represents the area of the open door in square feet. The increases in air flow through the storage rooms have not been in proportion to the increase in areas of intakes, but substantial differences

exist in favor of the open doors as a supplement to the air intakes proper.

It was stated in previous portions of this bulletin that the movement of air through the storage room is based on the fact that warm air is lighter than cold air. It was also shown, in Table 3, that increasing the height of the top of the outlet flue resulted in an increase in rate of air movement through the outlet, because of the fact that the columns of cool and warm air are higher, thus resulting in greater differences in the weights of the two columns. Efforts to obtain field records comparing rates of air movement at various temperature differences and for outlet flues of different heights were not successful. In order to obtain conditions suitable for a comparison of effects of temperature

Fig. 23.—Storage K. See Table 2 for description. A double wall of vitrified tile, such as exists here is unnecessarily expensive.

differences, windless nights with considerable temperature ranges are essential. These conditions did not obtain at any of the storages at times they were visited by members of the Station staff. Such attempts as were made to group tests conducted with various differences between outdoor and storage room temperatures, plainly showed that the results were more influenced by outdoor wind velocity than by temperatures. A comparison of rates of air movement through storage rooms having outlet flues of different heights is unsatisfactory for the reason that no two storages were operated under sufficiently similar conditions and it was not feasible to temporarily increase or decrease the height of a flue in any one storage.

The effect of velocity of the wind upon the rate and volume of air movement through the storage room is shown in Table 10. A number of other tests, although not strictly comparable, also show very clearly

that an increase in the velocity of the wind results in an increase in the rate of air movement in the storage, provided the house is given proper management. Furthermore, there is often a considerable movement of air through the storage rooms, even though the outdoor and indoor temperatures are practically the same, provided the outdoor wind velocity is two or three miles per hour.

**Table 10. Effect of Velocity of Wind on Quantity of Air Flow Through the Storage.**

| Test No. | Wind Velocity (Mi. per hr.) | Difference between Storage and Outdoor Temperatures | No. Air Changes in Storage Room per Hour |
|---|---|---|---|
| D 1 | Negligible | 5 | 5.5 |
| D 2 | 4.1 | 5 | 6.84 |
| D 3 | 6.8 | 3 | 11.63 |

## The Volume of Air Required to Cool Apples

The preceding discussion of the ventilation system has been designed to show what factors may influence the rate of air movement through the storage room. However, a knowledge of how to increase or decrease the number of air changes in a given period is of little value unless something is known with regard to the volume of air of a certain temperature that is required to pass through and about a quantity of fruit at a higher temperature to effect a given cooling of the fruit.

The results of four air flow tests of 11 to 13 hours' duration appear in Table 11. A volume of cool air 82 to 147 times the net volume of the fruit was required to reduce the temperature of the apples one degree, or, expressed differently, 41 to 73 cubic feet of air reduced the temperature of a bushel of apples one degree when the air was 3° to 9° F. lower in temperature than the fruit. The smaller volumes of cool air required to effect a unit of cooling of the apples in Tests C 3 and D 7 are evidently due to the fact that there were greater differences between the outside and storage air temperatures at these two storages than at those where Tests A 7 and E 7 were conducted. Theoretically, considerable differences between indoor and outdoor air temperatures should require a smaller volume of air of a given temperature to result in a specific cooling of the fruits than small temperature differences. The results actually obtained are in conformity to the hypothesis. Further tests to determine the volume of air at various temperatures that are necessary to cool apples through certain ranges of temperatures are contemplated under control conditions, and it is expected that such results will enable one to make more specific recommendations with regard to number and sizes of intakes and outlets for storages of various sizes.

**Table 11. Volume of Air Necessary to Cool Apples.**

| Tests No. | No. air changes in storage room | Mean difference between outdoor and storage temp. | Average temp. of apples at beginning | Average temp. reduction | No. cu. ft. of air required to cool one bu. apples 1° F. |
|---|---|---|---|---|---|
| D 7 | 34 | 8° F. | 45.0 F. | 3.0 | 41 |
| A 7 | 47 | 6° F. | 39.7 F. | 1.5 | 60 |
| C 3 | 47 | 9° F. | 43.0 F. | 1.25 | 42 |
| E 7 | 34 | 3° F. | 34.5 F. | 1.0 | 73 |

Based on the information at hand, it may be assumed that an average of 50 cubic feet of air under ordinary fall conditions, are required to cool a bushel of apples one degree, when there is a temperature difference of 4° or 5° F. If 2.5 cubic feet of storage space are allowed for each bushel of apples, it would then be necessary to secure the equivalent of 25 air changes in the storage room to obtain one degree of temperature reduction in the apples. Allowance must be made for such warming of the storage air and fruit as will result from workmen being in the room, entrance of heat during the day when persons are passing in and out through the doors or when fruit is being carried into the room, and also for the entrance or absorption of heat through the walls, ceiling and floor when the outdoor temperatures are higher than those in the storage room. The equivalent of three air changes in the room per hour, then, would probably not reduce the temperature of the fruit to exceed one degree per night under the conditions usually encountered in well constructed and well managed, air-cooled storages.

Fig. 24.—Storage L. See Table 2 for description. The cold air intakes, one of which is shown on the right of the door, are too small to serve the purpose for which they were intended. The concrete wall has not been water proofed.

## Recommendations for Air Intake and Outlet Areas

The tests, as a whole, indicate that a recommendation of one square foot of air intake area, exclusive of doors, for each 700 cubic feet of storage volume and one square foot of outlet area for each 1,200 cubic feet of storage room volume, will, under the conditions usually encountered in Michigan, result in an air movement equivalent to three complete changes of air per hour in the room. If the storage house is to have a full second story, the size of the air outlets may be reduced 25 to 35 per cent or to a basis of one square foot of outlet area to each 1,600 to 2,000 cubic feet of storage room volume because the outlet flues are higher (See Table 3).

The size of the intakes should not be less than 18 by 24; 18 by 30 or

even 20 by 30 inches would be preferable. If the intakes are 18 by 30 inches in size, one of them should suffice for each 2,500 cubic feet of storage volume. The air outlets should never be less than two feet square, even in houses with a full second story, and for one-story buildings such sizes as three feet square, three by four feet, and even four by four feet are better because of the smaller amount of friction involved.

Table 12 is suggestive of the number and sizes of air intakes and outlets suitable for houses of one story, above which is a roof with a pitch of one foot in three. The ridge of the roof would thus be 18 to 20 feet above the ground level of an above-ground storage. If the ridge of the roof is to be about 30 feet above the ground line, the outlets may be made 25 per cent smaller, or if it is to be 35 to 40 feet, the size of the outlets may be reduced 35 per cent of that suggested in the table. The recommendations are for storage rooms twelve feet in height. All dimensions and sizes are for inside measurements. The intakes should be located on at least three sides of the building and should be spaced at regular intervals. A choice of two sizes of air outlets is offered for each storage, except the one of 7,500 bushels capacity. All outlets are of such sizes that friction will play but a small part in retarding the rate of air movement.

**Table 12. Some Suggestions for Number and Sizes of Air Intakes and Air-Outlets for Storages of One Story.**

| Capacity (bus.) | Volume (cu. ft.) | Dimensions Storage Room (ft.) | No. of Intakes | Size of Intakes (in.) | No. of Outlets | Size of Outlets (in.) |
|---|---|---|---|---|---|---|
| 5000 | 12500 | 26 x 40 | 5 | 18 x 30 | 2<br>1 | 30 x 30<br>36 x 40 |
| 7500 | 18700 | 30 x 52 | 7 | 18 x 30 | 2 | 30 x 36 |
| 10000 | 25200 | 34 x 62 | 10 | 18 x 30 | 3<br>2 | 30 x 34<br>36 x 42 |
| 12500 | 31100 | 36 x 72 | 12 | 18 x 30 | 3<br>2 | 36 x 36<br>42 x 42 |
| 15000 | 37400 | 38 x 82 | 15 | 18 x 30 | 4<br>3 | 32 x 36<br>38 x 40 |
| 20000 | 48000 | 40 x 100 | 18 | 20 x 30 | 5<br>4 | 32 x 36<br>36 x 40 |

## HUMIDITY

When the air of a storage room is too dry, the apples lose moisture and wilt or shrivel. On the other hand, if the air in the storage is too humid, there may be condensation on the fruit and on the containers, walls, ceilings, etc., resulting in the growth of molds.

The humidity of the storage room, then, must be regulated to prevent wilting of the fruit or the growth of molds. It usually cares for itself during the fall months when the ventilation of the rooms is frequent, as a storage humidity similar to the average humidity of the outdoor air is easily maintained and is satisfactory from the standpoint of the pre-

vention of wilting and molding. One or the other of these storage troubles, however, is of frequent occurrence during the winter months.

Marble (9) states that apples held in a cellar storage until January 15 at relative humidities ranging from 60 to 73 per cent showed a little wilting, while those held at 90 per cent were perfect. A relative humidity of 60 per cent was found sufficiently low to prevent entirely the growth of molds. He states, also, that frequent ventilation prevents mold by keeping moisture from collecting on the fruit. Magness (6) states that humidity does not affect the rate of softening, acidity change, aroma or flavor of the apples, and that there is little danger from high humidities during the season of frequent ventilation.

The investigations of Magness and Burroughs (7) show that there is a wide variation in the tendency of different varieties of apples to wilt. Delicious, Rome Beauty, Winesap, and Yellow Newtown stand low humidity and rarely, if ever, wilt seriously in storage. Such varieties as Jonathan, Baldwin, York Imperial, and Spitzenburg often become badly wilted and shriveled when stored. Apples were found also to wilt

Fig. 25.—Storage O. See Table 2 for description. The apple storage is in the basement of the right half of this building. The basement of the left half constitutes an air-cooled potato storage. The cold air intakes are just above the ground line and most of them are under the loading platforms. A portion of the roof of one ventilator can be seen near the chimney.

less on the blushed than on the unblushed sides. These investigators conclude that about 85 per cent humidity is necessary to prevent wilting of the thin-skinned varieties when stored in open containers; if they are stored in barrels, wilting will not be serious even at 80 per cent humidity. Mold growths start in air above 90 per cent of saturation, so they believe 85 per cent humidity is nearest to the correct balance for apple storage.

The percentage of humidity is determined from temperature readings of both the wet and dry bulb thermometers of a sling psychrometer*. Humidity determinations should not be made when the intakes, doors, or outlets are open, because the humidity of the storage room air is then altered by air introduced from the outdoors. It is not believed that it is essential that a storage operator provide himself with one of these instruments because one may determine the humidity conditions in his storage by carefully and frequently examining the apples, espe-

*Tables for determining the relative humidity values from wet and dry bulb thermometer readings may be obtained from U. S. Weather Bureau Stations.

cially such wilt-susceptible varieties as Golden Russet, Baldwin, and Jonathan. If they show indications of loss of moisture, the floor of the storage room should be thoroughly wet for several days, or sheets or blankets should be hung in troughs of water located in the alleyways. If, on the other hand, molds and rots are developing on the fruits, the ventilators should be partly opened in the winter during a portion of the day when the outdoor temperatures are slightly lower than those in the storage room. It is preferable, however, to permit some growth of molds on parts of the building and the ground rather than to permit wilting of the fruit.

The most satisfactory method of regulating humidity in the air-cooled storage is to have earth or clay floors, even though they do conduct some heat into the room during the winter months. Most of the recently constructed air-cooled storages in Michigan have earth floors and in no case has there been serious wilting of the apples. A few of

Fig. 26.—Storage R. See Table 2 for description. The basement of this combination packing and storage house is used for storing fruit. In addition to the basement windows, which may serve as cold air intakes, there are five intakes at the farther end of the building, near the storage room floor.

the older storage houses and those which are remodeled farm buildings have concrete floors. Serious wilting occurred in one of the storages with a concrete floor during the storage season of 1922-1923, but this has been avoided since then by wetting the floors frequently. During 1923-1924 serious wilting of Roxbury Russet stored in paper-lined crates occurred in one of the storage rooms having a concrete floor, in spite of frequent sprinkling of the floor.

The points, relating to humidity, to bear in mind when planning and operating a storage are: The floor should be of earth so as to aid in regulating humidity. A relative humidity of 85 per cent will usually result in preventing the wilting of the apples and the growth of molds on the fruits. Frequent and thorough examinations of such thin-skinned varieties as Baldwin, Jonathan and the russets will indicate whether or not the humidity is too low. Wet the floors to increase the humidity and ventilate with colder air to decrease the humidity.

## STORAGE CONTAINERS FOR APPLES

Apples are stored in bins of permanent construction in a few storage houses but, on the whole, crates are the most satisfactory containers. The cost of constructing bins is lower than the cost of crates and similar types of containers, but the apples are handled more readily and with less bruising in containers which may be filled in the orchard and then placed in the storage without rehandling the fruit until it is desired to grade it for immediate sale. If they are used, bins should not be more than four feet in width and the apples should not be piled higher than four feet. The floors and sides of the bins should be constructed of three or four inch boards spaced about three-fourths of an inch apart so as to permit the air to come in contact with the apples to as great

Fig. 27.—The crates should be stacked in straights rows with two to four inches of space between rows. The outer crates should be at least eight inches from the wall.

an extent as possible. Six inches is none too great space to have between the bins, and the space between the bins and the walls should be at least eight inches in the clear.

In the discussion relating to humidity it was stated that wilting was more severe with apples in slatted crates than with those in barrels because the barrel is practically air tight. Marble (9) and Magness and Burroughs (7) found that the type of package has no effect upon the rate of respiration or the rate of softening of apples, indicating that the fruit cools as readily in the barrel as in the ventilated crate or any other ordinary apple container. Round bottom baskets have been used to a limited extent in a few Michigan storage houses, but they are not rigid enough and cannot be stacked satisfactorily in storage rooms of ordinary height. Some form of ventilated crate or orchard box, however, is proving popular and satisfactory as a storage container where the apples are to be graded at the time they are moved out of the storage,

because of their convenience, rigidity, ease of handling and suitability for stacking.

Unless a permanent false floor has been built, it is necessary to lay some timbers on the dirt floor of the storage across which boards may be laid to support the stacks of fruit and thus keep the apples off the ground and permit a circulation of air under them. The crates should be stacked in straight rows extending from the middle alleyway to the sides of the room. Two or four inches is a satisfactory space to leave between rows of containers, but the space between the storage wall and the containers should be eight or ten inches wide. It is preferable not to pile fruit closer than two feet to the ceiling of the room because the warmer air of the room always occupies that portion. Furthermore, considerable unobstructed space below the ceiling is conducive to better air circulation in the room. Many temperature readings of fruits taken from the lowest and highest tiers of crates in several storages show an average difference of about two degrees, although in some cases the fruit near the ceiling was four to four and one-half degrees warmer than that near the floor. The tendency to pile the crates to within a few inches of the ceiling is far too common.

## HANDLING APPLES FOR STORAGE

Apples which are to be stored should be picked at the time the green under color or ground color changes from the characteristic green of the immature apples to a lighter green or slight yellow. Green fruit is more susceptible to apple scald and wilting, while over-ripe apples are

Fig. 28.—This combination packing house and basement storage is typical of many in operation in western New York. The basement windows, three of which are shown, are large and are usually located on opposite sides of the building. There are no outlet flues extending through the ceiling and roof. The wind blows into the storage room through the large openings on the windward side and passes out similar ones on the leeward side.

more subject to internal breakdown and mealiness and the life processes are more nearly completed.

The fruit should be handled carefully so as to avoid skin breaks, as these ruptures afford easy access for decay organisms to which common storage apples are more susceptible than those in cold storage. Ramsey and Dennis (11), Cotton and Faxon (5), and Baker (1) recommend leaving the apples in crates in the orchard until the morning after picking so as to cool them before placing them in the storage room. This not only results in quicker cooling of the newly picked fruit, but also avoids raising the temperature of the apples, previously placed in the storage room, through the addition of a quantity of warm apples, and avoids keeping the storage doors open during the warmer portions of the day. More recently, Marble (9) reports investigations showing that apples held in an open shed until the first week in November were cooler than those held in his cellar storage, and he recommends that early maturing varieties like Wagener be held outdoors, where they may be protected from the sun and rain, until the storage room temperature is reduced to 40° F. He states that the temperatures under such conditions are higher during the day, but are enough lower during the night to more than counterbalance the warmer parts of the day. This practice is not recommended for Michigan, however, because of the danger of sudden drops in outdoor temperatures which may freeze the fruit before it can be moved into the storage. Burroughs (2), working at the Marble Laboratory, found that Wageners soften more slowly on the tree than in common storage and that the date of picking this variety during a warm fall may well be delayed ten days to two weeks. This practice

Fig. 29.—Storage C. A good storage was constructed in one end of this large barn. The original barn windows serve as cold air intakes. The four ventilating flues are too small to afford sufficient flow on still nights. See table 2 for description.

would also result in better color and quality and a greater freedom from scald. Magness (not published) states that, for common storages, picking should be delayed as long as the fruit is sticking to the tree in a satisfactory manner, because the fruit softens and ripens distinctly faster in common storage at the prevailing temperatures than it does on the tree.

## THE MANAGEMENT OF AIR-COOLED STORAGE

The usual practice is to stack ungraded apples in the storage room and do the grading at the time they are marketed. This practice is satisfactory for well grown and carefully handled apples and it enables the

Fig. 30.—Storage H. One corner of this large barn basement was partitioned off and insulated. It has not proved a satisfactory storage for two reasons: (1) there are neither outlet flues nor provision for taking advantage of wind because of the three air openings are all on the same side of the room, and (2) it has been almost impossible to maintain the humidity high enough to prevent wilting. See Table 2 for description.

fruit grower to maintain a larger picking crew than would otherwise be possible in many of the fruit sections. Furthermore, where community packing houses have air-cooled storages, apples delivered in excess of the daily packing capacity may be held ungraded in the storage rooms until after the deliveries from growers have discontinued or even until it is desired to market the apples, before they are graded.

The length of the storage season for the apples depends upon how early the temperature of the storage room is lowered to 32° or 34° F. and, in turn, the time required to lower the temperature of the fruit depends on the outdoor temperatures and the management of the storage. The latter is entirely under the control of the manager and, for the most part, consists in seeing that the air intakes, doors and outlets are promptly opened when the outdoor temperatures decline below

those of the storage room and in seeing that all air intakes and outlet doors are closed tightly when the outdoor temperatures are higher than those in the storage. In other words, advantage must be taken of the full amount of time when outdoor temperatures are lower than those in the storage until the temperature of the apples is below 35° F. It is therefore essential that reliable thermometers be placed outside the storage and near the center of the storage room. After the temperature of the apples has been reduced to between 32° and 35° F., an occasional ventilation may be necessary to maintain the desired temperature, but the maintenance of the proper humidity becomes the more important responsibility of the manager.

Occasionally a greater volume of air movement through the storage room will obtain if the air intakes are open on only the windward sides of the storage because of the tendency of the wind under such conditions, to blow across the room rather than to make its exit through the regular air outlets. This condition is more likely to occur in storages having false floors because the wind meets with less resistance in blowing across the room, underneath the false floor, than in passing upward through the stacks of apples. A number of tests showing the management of the storage should be governed to some extent by the direction and velocity of the outdoor winds are reported in Table 13.

**Table 13. Effect of Storage House Management Practices, in Presence of Winds, on Quantity of Air Movement.**

| Group | Test No. | Direction of Wind | Velocity (mi. per hr.) | Sides of Building on which Intakes or Doors were Open | | No. Air Changes per hour in Storage Room |
|---|---|---|---|---|---|---|
| | | | | Intakes | Doors | |
| XXII | A 2 | S | 15.0 | E & W | S | 7.34 |
| | A 3 | S | 15.0 | E & W | None | .04 |
| XXIII | A 4 | S | 1.9 | None | N & S | 11.36 |
| | A 5 | S | 1.9 | E & W | N & S | 9.06 |
| XXIV | D 4 | NW | 6.8 | N | None | 4.61 |
| | D 5 | NW | 6.8 | N & S | None | 2.0 |
| XXV | E 1 | Negligible | 0 | All | N | 9.05 |
| | E 2 | NW | 5.7 | All | N | 8.39 |
| XXVI | E 4 | NW | 1.5 | All | None | 3.58 |
| | E 5 | NW | 1.5 | S & E | None | 0.0 |
| | E 6 | NW | 1.5 | N & W | None | 2.48 |

In storage A the intakes are all located along the east and west sides of the building, but a large door is located in the north end and a small one in the south end. Group No. XXII (Table 13) shows that during a 15-mile south wind the regular air intakes of this storage practically failed to function and that a large volume of air entered a small doorway on the windward end of the building. This is, incidentally, a good reason for placing air intakes on the ends as well as along the sides of the building. In the tests of Group XXIII the wind was also blowing from the south but at only one-eighth the velocity recorded for the tests of Group XXII. Nevertheless, the east and west side air intakes not only failed to increase the air movement but hindered it.

Storage D has a false floor above the air intakes and the tests in Group XXIV show that better results were obtained during a seven mile wind when only the air intakes and doors on the windward side of the building were opened. The tests of Group XXV show a greater quantity of air flow through the storage room with no wind than while a 5.7 mile wind was blowing. In Test E2 the wind blew into the storage through intakes located on the north and west sides while on the south and east sides the air movement was outward rather than inward. Tests E4, E5, and E6 (Group XXVI) show that even in a wind of 1.5 miles little, if any, air was admitted through the intakes on the leeward sides of the building. Thus, the storage house manager must exercise considerable judgment in determining whether better results may be obtained by opening all the intakes and doors or only those on the windward sides of the storage building.

## COSTS AND RETURNS

Few air-cooled storages in the Pacific Northwest have proved unsatisfactory, according to Ramsey and Dennis (11); these failures were due either to improper construction or to inadequate insulation. A ten year program adopted by the Massachusetts Fruit Growers' Association (4) includes the following quotation: "Every grower whose annual production of winter apples totals 300 barrels should be equipped for handling his fruit in storage." No owner of a modern air-cooled storage in Michigan would dispense with one unless perhaps a cold storage were available.

The cost of an air-cooled storage depends somewhat on the kind of materials used in construction, the size and the extent of the building above the storage room. The costs of constructing storages A, D, E, F, G, K, L, N and R have ranged from 25 to 40 cents per bushel of storage capacity, and all of these storages with the exception of the first

Fig. 31.—Storage Q. See Table 2 for description. This building was constructed and operated as a canning factory. It was transformed into a storage house in 1924.

have been constructed in 1922, 1923 or 1924. The cost of the better constructed storages has been 35 to 40 cents per bushel of storage capacity and this range is the amount that one should assume in planning to erect a well constructed storage of 8,000 bushels capacity or larger.

The profits accruing from the operation of an air-cooled storage vary considerably in different parts of the state, but in the main depend on the manner in which the apples are marketed. The fruit grower who supples a local market or has a trade which comes to the farm for the apples usually can figure a larger profit due to the operation of the storage than the grower or organization that must follow the usual course in marketing in car lots. The owner of one of the older storages states that there have been three seasons in any one of which the profits of a season's operations paid the cost of constructing his storage house. Another owner says that his 10,000 bushel storage paid for itself during the first season of operation. Others have considered their storages very good investments, although it has been impossible to state the profits in dollars and cents.

The cost of operation of an air-cooled storage is very slight. Interest on the investment should not exceed two and one-half cents per bushel of capacity per year and other operation expenses such as electric light, labor involved in opening and closing the ventilators, insurance, depreciation and repairs will not run the total costs per bushel very high. In fact, the depreciation and repair charge, as well as the insurance rate, on a building of such types of construction as were employed in storages A, E and K are almost negligible. One storage owner did not have sufficient apples of his own to fill his storage room in 1922 and let a neighbor have space at the rate of ten cents per crate for the storage season, which he considered very profitable. A charge of ten cents per bushel is equivalent to a return of fully 25 per cent on the investment in a well constructed storage.

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# APPENDIX.

**Table 14. Daily Maximum and Minimum Outdoor and Storage Room Temperatures for Storage A During the Season of 1922-1923.**

| Date | Outdoor Temperature | | | Storage Temperature | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Range | Maximum | Minimum | Range |
| 10-28 | 55 | 41 | 14 | 47 | 44 | 3 |
| 29 | 69 | 40 | 29 | 44½ | 44 | ½ |
| 30 | 60 | 40 | 20 | 44½ | 43½ | 1 |
| 31 | 57 | 39 | 18 | 43½ | 43 | ½ |
| Average | 60.25 | 40 | 20.25 | 44.87 | 43.62 | 1.25 |
| 11- 1 | 61 | 39 | 22 | 43½ | 43 | ½ |
| 2 | 57 | 50 | 7 | 44½ | 43½ | 1 |
| 3 | 59 | 49 | 10 | 46 | 44½ | 1½ |
| 4 | 56 | 49 | 7 | 46 | 46 | 0 |
| 5 | 62 | 46 | 16 | 47 | 46 | 1 |
| 6 | 61 | 49 | 12 | 48 | 46 | 2 |
| 7 | 49 | 41 | 8 | 46 | 44 | 2 |
| 8 | 48 | 36 | 12 | 44 | 43½ | ½ |
| 9 | 45 | 33 | 12 | 43½ | 40½ | 3 |
| 10 | 53 | 35 | 18 | 42½ | 41½ | 1 |
| 11 | 59 | 46 | 13 | 44½ | 42½ | 2 |
| 12 | 53 | 39 | 14 | 44½ | 43 | ½ |
| 13 | 47 | 38 | 9 | 43 | 40 | 3 |
| 14 | 55 | 41 | 14 | 44 | 41½ | 2½ |
| 15 | 42 | 39 | 3 | 42½ | 40½ | 2 |
| 16 | 48 | 38 | 10 | 41½ | 40 | 1½ |
| 17 | 54 | 39 | 15 | 41 | 39½ | 1½ |
| 18 | 48 | 42 | 6 | 41½ | 40½ | 1 |
| 19 | 47 | 37 | 10 | 42 | 40½ | 1½ |
| 20 | 37 | 31 | 6 | 42 | 40½ | 1½ |
| 21 | 37 | 32 | 5 | 40½ | 38½ | 2 |
| 22 | 37 | 32 | 5 | 38½ | 37½ | 1 |
| 23 | 47 | 36 | 11 | 38 | 37 | 1 |
| 24 | 36 | 25 | 11 | 35 | 35 | 2 |
| 25 | 31 | 26 | 5 | 35½ | 34 | 1½ |
| 26 | 32 | 28 | 4 | 35½ | 33 | 1½ |
| 27 | 35 | 28 | 7 | 35 | 34 | 1 |
| 28 | 34 | 25 | 9 | 35 | 34 | 1 |
| 29 | 42 | 29 | 13 | 35 | 34 | 1 |
| 30 | 59 | 35 | 24 | 37 | 35 | 2 |
| Average | 47.7 | 37.1 | 10.6 | 41.41 | 39.96 | 1.45 |
| 12- 1 | 59 | 30 | 29 | 37 | 36½ | ½ |
| 2 | 44 | 27 | 17 | 37 | 36 | 1 |
| 3 | 48 | 33 | 15 | 37 | 37 | 0 |
| 6 | 27 | 17 | 10 | 33½ | 32 | 1½ |
| 7 | 37 | 27 | 10 | 34 | 33 | 1 |
| 8 | 48 | 20 | 28 | 33½ | 33½ | 0 |
| 9 | 26 | 17 | 9 | 34 | 33½ | ½ |
| 10 | 34 | 17 | 17 | 34½ | 34 | ½ |
| 11 | 41 | 29 | 12 | 34½ | 34½ | 0 |
| 12 | 31 | 10 | 21 | 34½ | 34 | ½ |
| 13 | 19 | 12 | 7 | 35 | 34 | 1 |
| 14 | 23 | 17 | 6 | 35½ | 35 | ½ |
| 15 | 19 | 12 | 7 | 35½ | 35 | ½ |
| 16 | 26 | 9 | 17 | 35 | 35 | 0 |
| 17 | 25 | 9 | 16 | 35 | 34½ | ½ |
| Average | 33.8 | 19.06 | 14.73 | 35.03 | 34.5 | .53 |
| 1- 1 | 30 | 27 | 3 | 35½ | 35 | ½ |
| 2 | 32 | 26 | 6 | 35 | 35 | 0 |
| 3 | 30 | 22 | 8 | 35 | 35 | 0 |
| 4 | 32 | 22 | 10 | 35 | 35 | 0 |
| 5 | 32 | 20 | 12 | 35½ | 35 | ½ |
| 6 | 22 | 14 | 8 | 35½ | 35½ | 0 |
| 7 | 27 | 14 | 13 | 35½ | 35½ | 0 |
| 8 | 32 | 24 | 8 | 36 | 35 | 1 |
| 9 | 32 | 26 | 6 | 35½ | 35 | ½ |
| 10 | 26 | 14 | 12 | 36 | 35½ | ½ |
| 11 | 28 | 12 | 16 | 36 | 36 | 0 |
| 12 | 29 | 24 | 5 | 36½ | 36 | ½ |
| 13 | 32 | 21 | 11 | 36½ | 36 | ½ |

**Table 14.**—*Continued*

| Date | Outdoor Temperature | | | Storage Temperature | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Range | Maximum | Minimum | Range |
| 14 | 39 | 32 | 7 | 36 | 36 | 0 |
| 15 | 36 | 26 | 10 | 36½ | 36 | ½ |
| 16 | 26 | 11 | 15 | 36½ | 36½ | 0 |
| 17 | 36 | 3 | 33 | 36½ | 36½ | 0 |
| 18 | 44 | 22 | 22 | 37 | 36½ | ½ |
| 19 | 25 | 17 | 8 | 37 | 36 | 1 |
| 20 | 44 | 25 | 19 | 36 | 36 | 0 |
| 21 | 26 | 21 | 5 | 36 | 36 | 0 |
| 22 | 25 | 16 | 9 | 36 | 36 | 0 |
| 23 | 31 | 12 | 19 | 36 | 36 | 0 |
| 24 | 34 | 23 | 11 | 36 | 35 | 1 |
| 25 | 31 | 20 | 11 | 35 | 35 | 0 |
| 26 | 38 | 25 | 13 | 35 | 35 | 0 |
| 27 | 28 | 24 | 4 | 35 | 35 | 0 |
| 28 | 32 | 25 | 7 | 35½ | 35 | ½ |
| 29 | 33 | 23 | 10 | 36 | 35½ | ½ |
| 30 | 34 | 17 | 17 | 36 | 35 | 1 |
| 31 | 39 | 32 | 7 | 35 | 35 | 0 |
| Average | 31.8 | 20.6 | 11.1 | 35.8 | 35.5 | .29 |
| 2- 1 | 39 | 25 | 14 | 35½ | [illegible] | ½ |
| 2 | 33 | 19 | 14 | 35½ | 35 | ½ |
| 6 | 20 | 15 | 5 | 34 | 34 | 0 |
| 7 | 29 | 16 | 13 | 34 | 34 | 0 |
| 8 | 35 | 15 | 20 | 34 | 34 | 0 |
| 9 | 20 | 13 | 7 | 34 | 34 | 0 |
| 10 | 28 | 18 | 10 | 34½ | 34 | ½ |
| 11 | 27 | 11 | 16 | 35 | 34 | 1 |
| 12 | 26 | 12 | 14 | 35 | 35 | 0 |
| 13 | 29 | 16 | 13 | 35 | 34 | 1 |
| 14 | 16 | 2 | 14 | 34 | 34 | 0 |
| 15 | 13 | 4 | 9 | 34 | 33 | 1 |
| 16 | 14 | 6 | 8 | 33 | 32½ | ½ |
| 17 | 12 | 5 | 7 | 32½ | 32½ | 0 |
| 18 | 17 | 8 | 9 | 32½ | 32 | ½ |
| 19 | 27 | 15 | 12 | 33 | 32½ | ½ |
| Average | 24 | 12.5 | 11.5 | 34.09 | 33.72 | .37 |

Note: The thermograph was not in operation on the days for which no temperatures are given.

**Table 15. Daily Maximum and Minimum Outdoor and Storage Room Temperatures for Storage A During the Season of 1923-1924.**

| Date | Outdoor Temperature | | | Storage Temperature | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Range | Maximum | Minimum | Range |
| 10–17 | 60 | 55 | 5 | 54 | 53 | 1 |
| 18 | 59 | 49 | 10 | 55 | 54 | 1 |
| 19 | 49 | 38 | 11 | 55 | 42 | 13 |
| 20 | 38 | 36 | 2 | 42 | 40 | 2 |
| 21 | 47 | 31 | 16 | 45 | 37 | 8 |
| 22 | 52 | 30 | 22 | 45 | 37 | 8 |
| 23 | 53 | 29 | 24 | 43 | 33 | 10 |
| 24 | 55 | 34 | 21 | 46 | 38 | 8 |
| 25 | 51 | 39 | 12 | 47 | 44 | 3 |
| 26 | 41 | 38 | 3 | 45 | 43 | 2 |
| 27 | 44 | 38 | 6 | 46 | 42 | 4 |
| 28 | 43 | 39 | 4 | 46 | 43 | 3 |
| 29 | 47 | 36 | 11 | 47 | 44 | 3 |
| 30 | 36 | 26 | 10 | 44 | 39 | 5 |
| 31 | 36 | 27 | 9 | 41 | 36½ | 4½ |
| Average | 47.4 | 36.33 | 11.07 | 46.73 | 41.7 | 5.03 |
| 11– 1 | 45 | 27 | 18 | 40 | 36 | 4 |
| 2 | 50 | 32 | 18 | 43 | 35 | 8 |
| 3 | 51 | 34 | 17 | 42 | 40 | 2 |
| 4 | 45 | 40 | 5 | 42½ | 42 | ½ |
| 5 | 46 | 33 | 13 | 43½ | 42 | 1½ |
| 6 | 47 | 29 | 18 | 43½ | 42½ | 1 |
| 7 | 39 | 27 | 12 | 44 | 38 | 6 |
| 8 | 32 | 26 | 6 | 41 | 36 | 5 |
| 9 | 45 | 26 | 19 | 41½ | 38 | 3½ |
| 10 | 53 | 35 | 18 | 42 | 38 | 4 |
| 11 | 49 | 30 | 19 | 43 | 40 | 3 |
| 12 | 48 | 31 | 17 | 42 | 42 | 0 |
| 13 | 46 | 32 | 14 | 43 | 41 | 2 |
| 14 | 44 | 33 | 11 | 42 | 42 | 0 |
| 15 | 46 | 40 | 6 | 43 | 39 | 4 |
| 16 | 42 | 30 | 12 | 44 | 42 | 2 |
| 17 | 41 | 30 | 11 | 43 | 39 | 4 |
| 18 | 40 | 24 | 16 | 44 | 39 | 5 |
| 19 | 41 | 24 | 17 | 43 | 43 | 0 |
| 20 | 52 | 32 | 20 | 42 | 38 | 4 |
| 21 | 47 | 30 | 17 | 44 | 40 | 4 |
| 22 | 38 | 23 | 15 | 44 | 42 | 2 |
| 23 | 31 | 28 | 3 | 44 | 41 | 3 |
| 24 | 39 | 29 | 10 | 41 | 41 | 0 |
| 25 | 46 | 28 | 18 | 42 | 39 | 3 |
| 26 | 39 | 28 | 11 | 41 | 41 | 0 |
| 27 | 34 | 29 | 5 | 40 | 39 | 1 |
| 28 | 32 | 25 | 7 | 40 | 37 | 3 |
| 29 | 34 | 24 | 10 | 40 | 39 | 1 |
| 30 | 37 | 34 | 3 | 40½ | 39½ | 1 |
| Average | 42.63 | 29.76 | 12.87 | 42.28 | 39.70 | 2.58 |
| 12– 1 | 41 | 34 | 7 | 41 | 40½ | ½ |
| 2 | 41 | 24 | 17 | 41 | 39 | 2 |
| 3 | 33 | 25 | 8 | 39 | 36 | 3 |
| 4 | 35 | 30 | 5 | 41 | 39 | 2 |
| 5 | 35 | 32 | 3 | 39 | 38 | 1 |
| 6 | 37 | 28 | 9 | 39 | 37 | 2 |
| 7 | 46 | 25 | 21 | 39 | 36 | 3 |
| 8 | 45 | 36 | 9 | 40 | 39 | 1 |
| 9 | 45 | 29 | 16 | 41 | 40 | 1 |
| 10 | 40 | 28 | 12 | 41 | 39 | 2 |
| 11 | 37 | 25 | 12 | 39 | 38 | 1 |
| 12 | 40 | 26 | 14 | 42 | 35 | 7 |
| 13 | 39 | 17 | 22 | 41 | 35 | 6 |
| 14 | 33 | 14 | 19 | 36½ | 36½ | 0 |
| 15 | 34 | 23 | 11 | 36½ | 36½ | 0 |
| 16 | 42 | 26 | 16 | 37½ | 36½ | 1 |
| 17 | 32 | 25 | 7 | 39 | 37 | 2 |
| 18 | 45 | 27 | 18 | 39 | 35 | 4 |
| 19 | 45 | 34 | 11 | 39½ | 39 | ½ |
| 20 | 48 | 36 | 12 | 40½ | 39½ | 1 |
| 21 | 41 | 32 | 9 | 41 | 40½ | ½ |
| 22 | 35 | 29 | 6 | 41 | 40 | 1 |
| 23 | 31 | 22 | 9 | 40 | 39 | 1 |
| 24 | 32 | 19 | 13 | 40 | 39½ | ½ |
| Average | 39 | 27 | 12 | 39.73 | 37.94 | 1.79 |

**Table 16. Daily Maximum and Minimum Outdoor and Storage Room Temperatures for Storage E During the Season of 1923-1924.**

| Date | Outdoor Temperature | | | Storage Temperature | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Range | Maximum | Minimum | Range |
| 10–15 | 76 | 49 | 27 | 50 | 48 | 2 |
| 16 | 81 | 56 | 25 | 53 | 50 | 3 |
| 17 | 65 | 56 | 9 | 54 | 53 | 1 |
| 18 | 60 | 43 | 17 | 55 | 43 | 12 |
| 19 | 55 | 36 | 19 | 45 | 38 | 7 |
| 20 | 49 | 36 | 13 | 44 | 37 | 7 |
| 21 | 66 | 32 | 34 | 42 | 34 | 8 |
| 22 | 66 | 34 | 32 | 42 | 34 | 8 |
| 23 | 49 | 42 | 7 | 46 | 42 | 4 |
| 24 | 63 | 41 | 22 | 46 | 43 | 3 |
| 25 | 46 | 39 | 7 | 43 | 41 | 2 |
| 26 | 52 | 40 | 12 | 44 | 41 | 3 |
| 27 | 56 | 36 | 20 | 45 | 41 | 4 |
| 28 | 63 | 33 | 30 | 41 | 37 | 4 |
| 29 | 43 | 30 | 13 | 41 | 40 | 1 |
| 30 | 41 | 29 | 12 | 40 | 33 | 7 |
| 31 | 58 | 26 | 32 | 34 | 31 | 3 |
| Average | 58.17 | 38.7 | 19.47 | 45 | 40.35 | 4.65 |
| 11– 1 | 62 | 29 | 33 | 36 | 31 | 5 |
| 2 | 53 | 30 | 23 | 36 | 34 | 2 |
| 3 | 45 | 41 | 4 | 38 | 36 | 2 |
| 4 | 43 | 40 | 3 | 39 | 38 | 1 |
| 5 | 57 | 37 | 20 | 39 | 37 | 2 |
| 6 | 43 | 33 | 10 | 42 | 34 | 8 |
| 7 | 35 | 27 | 8 | 35 | 30 | 5 |
| 8 | 51 | 24 | 27 | 36 | 34 | 2 |
| 9 | 65 | 31 | 34 | 38 | 36 | 2 |
| 10 | 60 | 34 | 26 | 39 | 38 | 1 |
| 11 | 58 | 32 | 26 | 40 | 36 | 4 |
| 12 | 62 | 35 | 27 | 40 | 39 | 1 |
| 13 | 51 | 35 | 16 | 40 | 38 | 2 |
| 14 | 48 | 38 | 10 | 41 | 39 | 2 |
| 15 | 45 | 35 | 10 | 41 | 41 | 0 |
| 16 | 48 | 32 | 16 | 41 | 41 | 0 |
| 17 | 44 | 32 | 12 | 41 | 41 | 0 |
| 18 | 45 | 22 | 23 | 41 | 31 | 10 |
| 19 | 58 | 29 | 29 | 36 | 32 | 4 |
| 20 | 59 | 37 | 22 | 38 | 36 | 2 |
| 21 | 58 | 29 | 29 | 37 | 34 | 3 |
| 22 | 40 | 34 | 16 | 37 | 35 | 2 |
| 23 | 45 | 32 | 13 | 37 | 34 | 3 |
| 24 | 52 | 31 | 21 | 39 | 36 | 3 |
| 25 | 47 | 36 | 11 | 36 | 35 | 1 |
| Average | 50.96 | 32.6 | 18.36 | 38.52 | 35.84 | 2.68 |
| 12– 4 | 40 | 38 | 2 | 37 | 36 | 1 |
| 5 | 46 | 36 | 10 | 37 | 36 | 1 |
| 6 | 45 | 30 | 15 | 36 | 33 | 3 |
| 7 | 49 | 41 | 8 | 37 | 37 | 0 |
| 8 | 55 | 38 | 17 | 39 | 37 | 2 |
| 9 | 56 | 35 | 21 | 40 | 39 | 1 |
| 10 | 48 | 28 | 20 | 36 | 32 | 4 |
| 11 | 46½ | 29 | 17½ | 36 | 34 | 2 |
| 12 | 52 | 24 | 28 | 37 | 29 | 8 |
| 13 | 39 | 21 | 18 | 34 | 31 | 3 |
| 14 | 34 | 26 | 8 | 34 | 32 | 2 |
| 15 | 50 | 31 | 19 | 34 | 31 | 3 |
| 16 | 39 | 29 | 10 | 34 | 32 | 2 |
| 17 | 45 | 29 | 16 | 34 | 34 | 0 |
| 18 | 42 | 31 | 11 | 35 | 34 | 1 |
| 19 | 49 | 40 | 9 | 37 | 35 | 2 |
| 20 | 45 | 35 | 10 | 37 | 37 | 0 |
| 21 | 44 | 34 | 10 | 38 | 37 | 1 |
| 22 | 37 | 28 | 9 | 38 | 33 | 5 |
| 23 | 45 | 23 | 22 | 36 | 33 | 3 |
| 24 | 42 | 33 | 9 | 36 | 35 | 1 |
| 25 | 44 | 29 | 15 | 36 | 34 | 2 |
| 26 | 45 | 35 | 10 | 36 | 35 | 1 |
| 27 | 43 | 30 | 13 | 36 | 32 | 4 |
| 28 | 46 | 25 | 21 | 35 | 35 | 0 |
| 29 | 36 | 33 | 3 | 35 | 35 | 0 |
| 30 | 39 | 26 | 13 | 36 | 35 | 1 |
| 31 | 26 | 14 | 12 | 35 | 35 | 0 |
| Average | 43.83 | 30.39 | 13.44 | 36.1 | 34.2 | 1.89 |

**Table 16.**—*Continued*

| Date | Outdoor Temperature | | | Storage Temperature | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Range | Maximum | Minimum | Range |
| 1– 1 | 34 | 14 | 20 | 35 | 34½ | ½ |
| 2 | 33 | 17 | 16 | 35 | 35 | 0 |
| 3 | 24 | 10 | 14 | 35 | 34½ | ½ |
| 4 | 15 | —6 | 21 | 35 | 34½ | ½ |
| 5 | 20 | —12 | 32 | 34 | 33 | 1 |
| 6 | 33 | 20 | 13 | 33 | 33 | 0 |
| 7 | 42 | 20 | 22 | 33 | 33 | 0 |
| 8 | 46 | 31 | 15 | 34½ | 33 | 1½ |
| 9 | 42 | 36 | 6 | 35 | 34½ | ½ |
| 10 | 42 | 27 | 15 | 35 | 35 | 0 |
| 11 | 33 | 27 | 6 | 35 | 35 | 0 |
| 12 | 31 | 17 | 14 | 35 | 35 | 0 |
| 13 | 30 | 16 | 14 | 35½ | 35 | ½ |
| 14 | 41 | 9 | 32 | 35 | 34 | 1 |
| 15 | 37 | 29 | 8 | 35 | 35 | 0 |
| 16 | 29 | 15 | 14 | 35 | 34 | 1 |
| 17 | 30 | 13 | 17 | 34½ | 34 | ½ |
| 18 | 32 | 21 | 11 | 35 | 34½ | ½ |
| 19 | 22 | 4 | 18 | 35 | 34 | 1 |
| 20 | 4 | —12 | 16 | 34 | 32½ | 1½ |
| 21 | 39 | 10 | 29 | 32 | 31 | 1 |
| 22 | 45 | 23 | 22 | 32 | 31 | 1 |
| 23 | 34 | 20 | 14 | 32 | 32 | 0 |
| 24 | 34 | 10 | 24 | 33 | 32 | 1 |
| 25 | 32 | —9 | 41 | 32½ | 31½ | 1 |
| 26 | 29 | —10 | 39 | 31½ | 31 | ½ |
| 27 | 36 | 14 | 22 | 31 | 30 | 1 |
| 28 | 35 | 32 | 3 | 31½ | 31 | ½ |
| 29 | 34 | 31 | 3 | 33 | 31½ | 1½ |
| 30 | 37 | 28 | 9 | 33 | 33 | 0 |
| 31 | 46 | 28 | 18 | 32 | 31 | 1 |
| Average | 32.93 | 15.26 | 17.67 | 33.77 | 33.16 | .61 |
| 2– 1 | 32 | 29 | 3 | 33 | 32 | 1 |
| 2 | 32 | 30 | 2 | 33 | 33 | 0 |
| 3 | 30 | 22 | 8 | 34 | 33 | 1 |
| 4 | 32 | 22 | 10 | 35 | 34 | 1 |
| 5 | 28 | 20 | 8 | 35 | 35 | 0 |
| 6 | 28 | 17 | 11 | 35 | 35 | 0 |
| 7 | 33 | 12 | 11 | 34½ | 34½ | 0 |
| 8 | 29 | 11 | 18 | 34½ | 34½ | 0 |
| 9 | 39 | 24 | 15 | 34½ | 34 | ½ |
| 10 | 34 | 18 | 16 | 34 | 34 | 0 |
| 11 | 32 | 19 | 13 | 34½ | 34 | ½ |
| 12 | 32 | 21 | 11 | 34½ | 34½ | 0 |
| 13 | 39 | 24 | 15 | 35 | 34½ | ½ |
| 14 | 28 | 12 | 16 | 35 | 34 | 1 |
| 15 | 29 | 11 | 18 | 34 | 34 | 0 |
| 16 | 33 | 20 | 13 | 34 | 34 | 0 |
| 17 | 40 | 13 | 27 | 34 | 33 | 1 |
| 18 | 29 | 17 | 12 | 33 | 33 | 0 |
| 19 | 29 | 17 | 12 | 33 | 33 | 0 |
| 20 | 34 | 13 | 21 | 33 | 32½ | ½ |
| 21 | 44 | 10 | 34 | 32½ | 32 | ½ |
| 22 | 37 | 7 | 30 | 32 | 32 | 0 |
| 23 | 41 | 16 | 25 | 32 | 32 | 0 |
| 24 | 40 | 15 | 25 | 33 | 32 | 1 |
| 25 | 44 | 6 | 38 | 33 | 32½ | ½ |
| 26 | 44 | 17 | 27 | 34 | 33 | 1 |
| 27 | 41 | 22 | 19 | 35 | 34 | 1 |
| 28 | 40 | 21 | 19 | 35 | 34 | 1 |
| Average | 34.75 | 17.35 | 15.39 | 33.89 | 33.46 | .43 |

**Table 17. Daily Maximum and Minimum Outdoor and Storage Room Temperatures for Storage E, Season of 1924-1925.**

| Date | Outdoor Temperature | | | Storage Temperature | | |
|---|---|---|---|---|---|---|
| | Maximum | Minimum | Range | Maximum | Minimum | Range |
| 10–29 | 75 | 48 | 27 | 48½ | 46½ | 2 |
| 30 | 76 | 41 | 35 | 48½ | 46½ | 2 |
| 31 | 78 | 45 | 33 | 49 | 45 | 4 |
| Average | 76.33 | 44.66 | 31.66 | 48.66 | 46 | 2.66 |
| 11– 1 | 68 | 45 | 23 | 50½ | 46½ | 4 |
| 2 | 74 | 40 | 34 | 49 | 43 | 6 |
| 3 | 55 | 31 | 24 | 49 | 39 | 10 |
| 4 | 57 | 26 | 31 | 43½ | 35 | 8½ |
| 5 | 69 | 39 | 30 | 43 | 38 | 5 |
| 6 | 74 | 54 | 20 | 46 | 43 | 3 |
| 7 | 67 | 37 | 30 | 47 | 40 | 7 |
| 8 | 39 | 33 | 6 | 40 | 37 | 3 |
| 9 | 56 | 29 | 27 | 37 | 32 | 5 |
| 10 | 65 | 31 | 34 | 39 | 33 | 6 |
| 11 | 65 | 42 | 23 | 41 | 39 | 2 |
| 15 | 49 | 25 | 24 | 34 | 28 | 6 |
| 16 | 40 | 21 | 19 | 35 | 28 | 7 |
| 17 | 35 | 20 | 15 | 32½ | 28 | 4½ |
| 18 | 42 | 21 | 21 | 30 | 29½ | ½ |
| 19 | 41 | 26 | 15 | 36 | 34 | 2 |
| 20 | 54 | 32 | 22 | 38 | 36 | 2 |
| 22 | 41 | 32 | 9 | 40 | 38 | 2 |
| 23 | 36 | 32 | 4 | 39 | 37 | 2 |
| 24 | 35 | 27 | 8 | 38½ | 32½ | 6 |
| 25 | 29 | 24 | 5 | 34 | 30 | 4 |
| 26 | 47 | 25 | 22 | 36 | 34 | 2 |
| 27 | 36 | 29 | 7 | 36 | 32 | 4 |
| 28 | 33 | 19 | 14 | 35 | 33 | 2 |
| 29 | 33 | 19 | 14 | 35 | 34 | 1 |
| 30 | 32 | 15 | 17 | 35½ | 35 | ½ |
| Aver. for 26 days | 48.92 | 29.77 | 19.15 | 39.2 | 35.17 | 4.03 |
| 12– 1 | 30 | 13 | 17 | 34½ | 34 | ½ |
| 2 | 36 | 15 | 21 | 35 | 34½ | ½ |
| 3 | 41 | 37 | 4 | 36½ | 35 | 1½ |
| 4 | 36 | 29 | 7 | 36½ | 36 | ½ |
| 5 | 42 | 30 | 12 | 38 | 36½ | 1½ |
| 6 | 43 | 35 | 8 | 39 | 38 | 1 |
| 7 | 40 | 33 | 7 | 40 | 38 | 2 |
| 8 | 53 | 40 | 13 | 44 | 40 | 4 |
| 9 | 40 | 24 | 16 | 43 | 35 | 8 |
| 10 | 29 | 23 | 6 | 39 | 36 | 3 |
| 11 | 32 | 24 | 8 | 37 | 36 | 1 |
| 12 | 36 | 28 | 8 | 37½ | 36 | 1½ |
| 13 | 37 | 25 | 12 | 38½ | 36 | 2½ |
| 14 | 25 | 17 | 8 | 38 | 36½ | 1½ |
| 15 | 28 | 22 | 6 | 37 | 36½ | ½ |
| 16 | 41 | 25 | 16 | 38 | 37 | 1 |
| 17 | 38 | 27 | 11 | 38½ | 35 | 3½ |
| 18 | 31 | 25 | 6 | 37½ | 35½ | 2 |
| 19 | 32 | 14 | 18 | 37½ | 37 | ½ |
| 20 | 16 | 10 | 6 | 37½ | 36 | 1½ |
| 21 | 19 | 10 | 9 | 36 | 35½ | ½ |
| 22 | 26 | 14 | 12 | 35½ | 35½ | 0 |
| 23 | 26 | 14 | 12 | 35½ | 35½ | 0 |
| 24 | 28 | 10 | 18 | 35½ | 35½ | 0 |
| 25 | 15 | —12 | 27 | 35½ | 35 | ½ |
| 26 | 21 | —8 | 29 | 35 | 33½ | 1½ |
| 27 | 20 | —6 | 26 | 33½ | 33½ | 0 |
| 28 | 15 | —12 | 27 | 33½ | 32½ | 1 |
| 29 | 19 | 3 | 16 | 32½ | 32 | ½ |
| 30 | 24 | 9 | 15 | 32½ | 32½ | 0 |
| 31 | 24 | 13 | 11 | 32½ | 32 | ½ |
| Aver. for Dec. | 30.42 | 17.13 | 13.29 | 36.77 | 35.43 | 1.37 |